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A FIELD STUDY OF BED ACTIVITY
IN THE LOWER RED DEER RIVER

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A FIELD STUDY OF BED ACTIVITY IN THE LOWER RED DEER RIVER" submitted by Nestor Bobey in partial fulfilment of the requirements for the degree of Master of Science.

SYNOPSIS

Quantitative data were obtained in a sand-bed reach of the Red Deer River, Alberta during ordinary summer stage for the study of bed activity and determination of hydraulic characteristics.

The general alternation and deformation of the mobile sand-bed with change in stage is described.

The forms of bed roughness as recorded with sonic sounding equipment and their change with change in stage is given in detail.

The growth and displacement of a scour hole at a sharp bend with rising stage and its subsequent retraction with falling stage is described. A local scour hole near an old truncated bridge pier is also described and discussed.

The Regime Equations are reviewed. The bed factor and side factor parameters are evaluated and the bed load charge is estimated.

Friction coefficients in terms of the Manning "n" and the Darcy-Weisbach "f" are evaluated for the study length.

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LIST OF SYMBOLS AND DEFINITIONS

rs	=	reference stage, an arbitrary inclined plane of slope 0.268 feet per 1000 feet which passes through geodetic elevation 2109.0 = rs + o at Dutchess Bridge, and corresponds to a discharge of approximately 2500 cfs along the lower Red Deer.
bfs	=	bankfull stage = rs + 12
gwl	=	geodetic water level
A	=	cross-sectional area in square feet
b _w	=	breadth of channel at water surface in feet
C	=	bed load charge, measured as dry weight per second of bed load divided by weight of water flow per second and reduced to parts per hundred thousand
d	=	average depth of channel in feet, A/b
D _{mm}	=	median particle size, by weight of a sediment sample in millimeters.
F	=	Froude number, V/\sqrt{gd}
F _b	=	bed factor, V^2/b
F _{bo}	=	the bed factor corresponding to a vanishingly small C
F _s	=	the side factor, V^3/b
f	=	Darcy-Weisbach friction factor
g _s	=	rate of bed load transport by weight per unit width of channel lbs/sec/ft
g	=	acceleration due to gravity, 32.2 ft/sec
K	=	$3.63 g^{0.25}$ from regime slope equation
(klm)	=	non-dimensional multiplier for practical application regime slope formula to rivers
n	=	Manning friction factor
q	=	discharge intensity = discharge per unit breadth = Q/b or Vd
Q	=	discharge rate in cu.ft./sec.

R = Reynold's number

S = average slope of water surface \approx slope of energy grade line

V = average velocity at a section in ft./sec.

ν = kinematic viscosity in ft.²/sec.

Z = regime slope parameter = $b^{1/6} S / F_{bo}^{1/12}$

CHAPTER I

INTRODUCTION

1.1 Purpose of Investigation

The principal aim of the study reported herein was to obtain and analyze field data on depth changes and associated bed-material movements in a 3-mile length of the lower Red Deer River. The study was envisaged as forming part of a general investigation of the channel regime of the river, which has already been reported in part (Neill and others, 1965). It was also envisaged as contributing data to the Canadian program for the International Hydrologic Decade, in connection with the item in that program which reads*

"5.5 Evolution of River Beds and Sedimentation

Tests of general theories of the self-adjustment of rivers with sand and gravel beds should be undertaken by a number of countries for various types of rivers. Quantitative regime surveys in sand and gravel rivers and laboratory, and large scale field model investigations, should be undertaken to develop transport laws valid in rivers. Analyses of effects of human interference with river regimes, and the causes and prevention of local erosion should be undertaken along with studies of sources and quantities of river sediments."

A secondary objective was to test the applicability of regime slope formulas to estimating bed-load transport in rivers at low to moderate stage. A similar analysis had already been made by Qureshi (1961) of a gravel-bed length of the Middle Red Deer.

1.2 Status of Present Information on River-bed Processes

It is presently recognized that understanding of river-bed processes

*From "Proposals for Canadian Participation in the I.H.D." N.R.C. Subcommittee on Hydrology, August 1963.

is deficient in many respects, that useful field data are extremely scanty, and that such information as exists is mainly qualitative. Neill (1964) has expressed dissatisfaction with the status of data collection and has suggested a list (Appendix 1) of essential information. Blench and Erb (1957) have emphasized the defects of even laboratory transport data. Blench (1955) has further emphasized the paucity of both laboratory and field transport information. Advances in basic knowledge would be of value to civil engineers for many purposes, such as design of bridge foundations against scour, design of river training works, highway bank protection, etc.

1.3 Selection of Study Length

The particular study length chosen on the lower Red Deer River near Duchess, shown on FIGURES 1.1 and 1.2, was selected because:

- i) scour and bed changes are believed to be most serious in sand-bed rivers, and the lower Red Deer is one of the major sand-bed rivers in Alberta;
- ii) the flood hydrology of the river had been summarized;
- iii) data was being compiled on its overall channel regime and morphology;
- iv) consideration of channel shift rates and regime slopes suggested that the bed might be highly active at moderate stages;
- v) the stratigraphic section (FIGURE 1.3) showed a depth of sand sufficient for full development of bed deformation;
- vi) the length contained a recent bridge structure and three old bridge piers, which could be used for observations of local scour near obstructions;

vii) the site was easily accessible.

It was hoped that a relatively high stage would occur during the investigation, for it would have given information on scour at high flows. However, the probability of one occurring was low, since the frequency of occurrence of bankfull discharge is of the order of once in 20 years. In fact, as will be shown, 1964 was a year of relatively low flows.

CHAPTER II

DESCRIPTION OF STUDY LENGTH

2.1 Geographic Setting

The Red Deer River rises in the eastern slopes of the Rocky Mountains and traverses the foothills region in a north-easterly direction to the vicinity of Red Deer City. There it changes course to a generally south-easterly direction, passing through the gently undulating plains of southern Alberta to join the South Saskatchewan River near Empress.

In the locality of the study length the river occupies a deep valley, which at present is about 4000 feet wide at prairie level. The modern river level, generally 200 to 250 feet below the surrounding plains, appears to be underlain with a thick deposition (up to 50 feet) of stratified silts and sands. Traces of coal are present. The modern river channel is well incised, has a bankfull width of about 600 feet, and meanders with a wavelength of about 1.5 to 2 miles across a flood plain confined by valley walls of bedrock about 2500 feet apart. Systematic downstream migration of the channel is evidenced by meander scrolls and natural levees.

Considering the smoothly graded longitudinal profile (Neill and others, 1965) the river may be termed a mature one. The exact geological history of the river is uncertain.

Climatically the area is cold-temperate, semi-arid with extremes of hot summers and cold winters. Vegetation is typical dry, short prairie grass with no tree or brush cover, except in the river valley where

scattered brush and trees occur. The river is frozen over and may be considered dead during the winter months, November to April.

Representative photographs of the river near the study length are included in the general report by Neill and others (1965).

2.2 Hydrologic Characteristics of River

To gain perspective of long term river behaviour some key hydrologic data are summarized in the following. The data are based on records of the Water Resources Branch, Department of Northern Affairs and National Resources, analyzed by the Research Council of Alberta. The content includes typical data of former years for purposes of comparison with the conditions of Summer 1964.

i)	Drainage area above Red Deer City	4,420 sq. miles
	Drumheller	9,660 " "
	Study length, approximately	13,000 " "
	Bindloss-Empress	16,800 " "
ii)	Mean annual flow: of long term approximately	2,200 cfs
	of 1964	1,750 cfs
iii)	Median annual peak discharge (mean daily)	14,000 cfs
	1964 instantaneous peak at Duchess Bridge	13,500 cfs
iv)	Estimated 100 year flood	90,000 cfs
v)	Ratio of 100 year to median annual flood	6.4
vi)	Estimated bankfull stage	35,000 cfs
vii)	Highest flow recorded in 1915 at Red Deer City	
	mean daily	55,000 cfs
	instantaneous peak	68,000 cfs
viii)	FIGURE 2.1 shows a selection of typical discharge hydrographs of former years at Red Deer City and the 1964 hydrograph for the study length.	

CHAPTER III

DESCRIPTION OF METHODS USED AND DATA OBTAINED

3.1 Crew and Equipment

The field work was performed by a three man crew, working over a 72 day period, from May 19th to July 29th, 1964. Approximately 1440 man hours of labor were expended.

The major pieces of equipment consisted of

- i) a one ton truck
- ii) a flat bottom boat with 6" to 8" draft, air screw driven by a 125 h.p. engine
- iii) a Bludworth echo-sounder complete with essential accessories
- iv) a velocity meter, Ott No. 765 complete with accessories
- v) a water level recorder, Stevens type A35
- vi) survey equipment, transit, level, chains, etc.
- vii) drag bucket bed material sampler

3.2 Horizontal Control Survey

A horizontal grid system of longitudinal "sailing lines" and transverse "fix lines", marked with targets and range poles was established for navigation control. The 3-mile study length was divided longitudinally into seven parts determined by river alignment and ground topography and designated (going upstream) as

Gopher Beach Division		
Bar	"	"
Alfalfa	"	"
X	"	"
Thorn	"	"
Fly	"	"
John's	"	"

Conventional survey methods were used. Map no. 1 (back cover) shows the dimensional details of the survey. FIGURE 3.1 illustrates a typical layout.

3.3 Stages, Discharges, and Velocities

A stage and discharge hydrograph for the working period is given in FIGURE 3.2. Stages were measured on an automatic water-level recorder mounted temporarily on a pier of the Highway 36 bridge, supplemented by stick gauge readings for the lower stages, when the recorder float was inclined to rest on the river bottom. Discharges were estimated by interpolating from official daily records at Drumheller (62 miles upstream) and Bindloss (103 miles downstream), supplemented by several current-meter surveys within the study length. A tentative stage-discharge curve for the highway bridge section is shown as FIGURE 3.3. Data on the discharge gaugings are given in TABLE 3.1, and some of the velocity distributions obtained in the course of these gaugings are shown in FIGURE 3.16.

3.4 Longitudinal Sonic Soundings

The sounding equipment was carried aboard the shallow draft, air screw driven boat. Sounding of the river bed was accomplished by navigating upstream along the established sailing lines by visual sightings of targets. The lateral error of sailing, which was affected by wind and cross currents, was estimated as up to 5 or 10 feet off line. Longitudinal distance control was maintained by visual sighting of the range poles marking the fix lines. The possible error in fixes is estimated as within 3 feet in 400 feet. FIGURE 3.1 illustrates the method.

Essentially three separate and successive surveys were made of the river-bed in the course of the season. These are designated herein as Tours 1, 2 and 3, and their timing and duration are shown in relation to the river hydrograph on FIGURE 3.2. TABLES 3.2, 3.3 and 3.4 show how much of the study area was covered by each tour, the exact time at which each sailing line was sounded, and the river stage and discharge at time of sounding. Tours 1 and 2 do not give complete coverage, in that the sections designated "X Beach" and "John's Beach" were missed. Tour 3 gives complete coverage but was actually divided into two parts separated by an interval of three days during which there was a substantial rise in stage.

It is recognised that the sounding data are not as complete or extensive as they might have been. This was mainly due to equipment breakdowns and other unforeseen difficulties.

FIGURES 3.4 to 3.12 inclusive show selected reproductions of the sounding charts recorded on the sonic instrument during the tours. The particular sailing lines reproduced are indicated in TABLES 3.2 to 3.4. Each figure sheet covers one sailing line throughout one division of the study length, and shows the charts for the three successive tours. FIGURES 3.9, 3.10 and 3.11 also include low-stage charts obtained in test runs prior to the start of Tour 1. On these charts the uppermost clear trace represents the river-bed. Where a second lower trace occurs, this represents a second reflection of the sonic signal and should be disregarded. The horizontal shadow that appears on some charts at a depth of around three feet does not represent a bed profile, but may have some connection with scattering of the signal by suspended material.

3.5 Cross-sections

A total of 19 channel cross-sections were surveyed along the study length, at approximately 800 foot intervals, on selected fix lines. Bank side portions were surveyed by conventional stadia methods. Water side portions were sonically sounded. FIGURE 3.13 shows all the cross-sections plotted with a vertical scale exaggeration of ten times. TABLE 3.5 summarizes the cross-sectional areas and water surface widths of each section for 2 foot increments of stage.

3.6 Slope Profile

A low-water surface slope profile was measured by levelling from temporary bench marks located on high ground and adjusting the data to correspond to July 26, p.m. TABLE 3.6 gives the data and FIGURE 3.14 shows a plot of the water surface, together with depths along the thalweg. The straight line fitted by eye through the plotted points is the average slope of the water surface and is taken to represent approximately the average energy grade line of the study length. The slope of this line is 0.268 per 1000 over the three mile reach, and varies from about 0.18 to 0.38 per 1000 over short subreaches.

3.7 Sampling of Bed and Bank Materials

Bed and bank material samples were taken at 51 locations as shown on Map. no. 1. A drag bucket was used to obtain the bed samples. Bank samples were obtained by digging with a hand shovel. Mechanical sieve grain size analysis was performed in the University soils laboratory.

TABLE 3.7 gives the sieve analyses of 16 bed samples along the deep-water channel. TABLE 3.8 gives similar data for 16 bed samples in

shallow water. TABLE 3.9 gives data for 19 bank samples. Average gradings are calculated for each group and plotted as cumulative size distribution curves on logarithmic probability paper (FIGURE 3.15). The median diameter of the composite deep-water bed sample is 0.34 mm, and the distribution curve plots approximately as a straight line (normal distribution) for about 90% of the sample weight. Blench (1952) has drawn attention to the frequent conformity of natural river sands to this type of distribution.

3.8 Soundings of Local Scour

The study length contains three old timber crib pier foundations, the remains of a bridge washed out by spring ice in 1947. They are located about 2000 feet downstream of the new bridge. A scour hole was found at the nose of the southernmost pier, and the area was sounded in detail. The results are presented along with the discussion in 4.7 following, together with data on scour at a sharp bend.

3.9 Water Temperatures

The following air and water temperatures were recorded at Jenner gauging station (50 miles downstream of the study length) during 1964:

	<u>Air</u>	<u>Water</u>	
9 May	62	52	°F
10 May	42	49	
11 May	56	50	
11 June	81	57	
14 July	92	61	

TABLE 3.1

STAGE-DISCHARGE OBSERVATIONS AT DUCHESS BRIDGE

<u>Point</u>			
1	May 8, 1964	Measured off North Duchess Bridge H. McPherson and crew Geodetic water level 2111.30 Q = 6150 cfs	rising stage
2	June 22, 1964	Measured off North Duchess Bridge Bobey and crew g.w.l. 2113.9 Q = 11,600 cfs	falling stage
3	June 26, 1964	Measured off boat and cable Bobey and crew g.w.l. 2112.2 Q = 7600 cfs	falling stage
4	July 11, 1964	Measured off boat and cable Bobey and crew g.w.l. 2110.9 Q = 4894 cfs	falling to rising
5	June 19, 1964	Measured off North Duchess Bridge McPherson, Neill and crew g.w.l. 2109.7 Q = 3400 cfs	
6	August 29, 1957	Bridge Branch File No. 7461 Dwg. #2410-C g.w.l. 2108.3 Q estimated as 1500 cfs Estimated bankfull stage from 1964 field work geod. elev. 2121 Estimated ranges of bankfull stage by others ¹ bankfull stage 2118 to 2121 discharge 30,000 to 40,000 cfs	
8	August 1954	Flood ^{1,2} g.w.l. estimated 2123, Q approximately 55,000 to 60,000 cfs.	

¹ Hydrology File - Red Deer River and "Hydrologic Data on Floods in the Red Deer River" an unpublished report by Research Council of Alberta, compiled by C.R. Neill and others, March 1964.

² "Channel regime of the lower Red Deer River" by Neill and others, April 1965.

TABLE 3.2

SOUNDING TIMES AND FLOW CONDITIONS - TOUR NO. 1

	SL	JUNE		Geod. W.L. at Bridge	Water Surface with respect to ref. stage	Discharge c.f.s.
Gopher Beach	1*	11	3:15 p.m.	2111.9	+ 2.9	7,400
	2*	11	3:30 p.m.	"	"	"
	3*	11	4:00 p.m.	"	"	"
Bar Beach	1*	12	7:00 a.m.	2111.3	+ 2.3	6,150
	2*	12	7:30 a.m.	"	"	"
	3*	11	5:00 p.m.	2111.8	+ 2.8	7,100
	4	12	7:30 a.m.	2111.3	+ 2.3	6,150
Alfalfa Beach	1	12	7:30 a.m.	2111.3	+ 2.3	6,150
	2	12		"	"	"
	3*	12		"	"	"
	4*	12		"	"	"
X Beach	1					
	2					
	3					
	4					
	5					
				Not sounded		
				- Ground survey not complete		
Thorn Beach	1	12		2111.2	+ 2.2	6,000
	2	12		"	"	"
	3	12		"	"	"
	4	12		"	"	"
	5	12		"	"	"
Fly Beach	1	12		2111.1	+ 2.1	5,700
	2	12		"	"	"
	3	12	12:00 noon	"	"	"
	4	12	12:20 p.m.	"	"	"
John's Beach	1					
	2					
	3					
	4					
	5					
	6					
				Not sounded		
				- Ground survey not complete		

* Sounding charts reproduced in FIGS. 3.4 to 3.12.

TABLE 3.3

SOUNDING TIMES AND FLOW CONDITIONS - TOUR NO. 2

	SL	JUNE		Geod. W.L. at Bridge	Water Surface with respect to ref. stage	Discharge c.f.s.
Gopher Beach	1*	24	8:30 a.m.	2113.4	+ 4.4	10,700
	2*	24	8:47 a.m.	"	"	"
	3*	24	9:08 a.m.	"	"	"
Bar Beach	1*	24	9:35 a.m.	2113.4	+ 4.4	10,700
	2*	24	9:50 a.m.	"	"	"
	3*	24	10:12 a.m.	"	"	"
	4	24		"	"	"
Alfalpa Beach	1	24	10:30 a.m.	2113.4	+ 4.4	10,700
	2	24	10:43 a.m.	"	"	"
	3*	24	11:00 a.m.	"	"	"
	4*	24	11:15 a.m.	"	"	"
X Beach	1					
	2					
	3					
	4					
	5					
				Not sounded - Ground survey not complete		
Thorn Beach	1	25	8:00 a.m.	2112.75	+ 3.8	9,400
	2	25		"	"	"
	3	25	8:30 a.m.	"	"	"
	4	25		"	"	"
	5	25		"	"	"
Fly Beach	1	25		2112.75	+ 3.8	9,400
	2	25		"	"	"
	3	25	10:00 a.m.	"	"	"
	4	25	10:30 a.m.	"	"	"
John's Beach	1					
	2					
	3					
	4					
	5					
	6					
				Not sounded - Ground survey not complete		

* Sounding charts reproduced in FIGS. 3.14 to 3.12.

TABLE 3.4

SOUNDING TIMES AND FLOW CONDITIONS - TOUR NO. 3

	<u>SL</u>	<u>JULY</u>		<u>Geod. W.L. at Bridge</u>	<u>Water Surface with respect to ref. stage</u>	<u>Discharge c.f.s.</u>
Gopher Beach	1*	3	11:30 a.m.	2110.1	+ 1.1	4,000
	2*	3	12:20 p.m.	"	"	"
	3*	3	12:30 p.m.	"	"	"
Bar Beach	1*	3	12:15 p.m.	2110.1	+ 1.1	4,000
	2*	3		"	"	"
	3*	3	1:00 p.m.	"	"	"
	4	3	1:10 p.m.	"	"	"
Alfaifa Beach	1	3		2110.1	+ 1.1	4,000
	2	3	1:25 p.m.	"	"	"
	3*	3	1:45 p.m.	"	"	"
	4*	3	2:00 p.m.	"	"	"
X Beach	1	7	9:07 a.m.	2112.9	+ 3.9	9,600
	2	7	9:20 a.m.	"	"	"
	3*	7	9:40 a.m.	"	"	"
	4	7	10:00 a.m.	"	"	"
	5	7	10:20 a.m.	"	"	"
Thorn Beach	1	4	10:00 a.m.	2110.1	+ 1.1	4,000
	2	4		"	"	"
	3	4	9:30 a.m.	"	"	"
	4	4	9:00 a.m.	"	"	"
	5	4	8:45 a.m.	"	"	"
Fly Beach	1	4	10:30 a.m.	2110.1	+ 1.1	4,000
	2	4	10:45 a.m.	"	"	"
	3	4	11:00 a.m.	"	"	"
	4	4	11:20 a.m.	"	"	"
John's Beach	1	8	1:00 p.m.	2112.1	+ 3.1	7,800
	2	8	1:12 p.m.	"	"	"
	3	8	1:24 p.m.	"	"	"
	4	8	1:36 p.m.	"	"	"
	5	8	1:48 p.m.	"	"	"
	6	8	2:00 p.m.	"	"	"

* Sounding charts reproduced in FIGS. 3.4 to 3.12.

WATER AREAS (A) AND SURFACE WIDTHS (b_W) OF SURVEYED
CHANNEL CROSS-SECTIONS
for 2-foot increments of stage

			<u>rs + 0</u>	<u>rs + 2</u>	<u>rs + 4</u>	<u>rs + 6</u>	<u>rs + 8</u>	<u>rs + 10</u>	<u>rs + 12</u>
GOPHER BEACH	FIX 1	A	690	1835	3090	4420	5830	7565	9370
		b_W	540	605	650	680	730	900	905
	3	A	1110	1825	2650	3650	4715	5935	7110
		b_W	340	375	450	550	575	585	590
	5	A	1190	1745	2465	3345	4280	4245	6240
		b_W	245	330	420	460	475	490	505
BAR BEACH	FIX 7	A	1530	2500	3490	4500	5545	6625	7720
		b_W	480	490	500	510	535	545	550
	9	A	1470	2470	3485	4510	5540	6575	7615
		b_W	495	505	510	515	515	520	520
	11	A	1380	2360	3460	4710	6045	7420	8805
		b_W	480	500	600	650	685	690	695
ALFALFA BEACH	FIX 12	A	1120	2110	3190	4354	5530	6740	7970
		b_W	480	510	570	585	600	610	620
	15	A	1025	1925	2985	4115	5290	6485	7685
		b_W	290	510	550	580	595	600	600
	19	A	1160	2360	3590	4850	6135	7425	8715
		b_W	590	610	620	640	645	645	645
X BEACH	FIX 22	A	1020	2150	3430	4755	6090	7435	8790
		b_W	510	620	660	665	670	675	680
THORN BEACH	FIX 1	A	1690	2730	3780	5675	7190	8710	10,235
		b_W	520	520	530	755	760	760	765
	4	A	1460	2440	3480	4615	5815	7040	8285
		b_W	480	500	540	595	605	620	635
	7	A	1450	2370	3320	4290	5270	6260	7250
		b_W	450	470	480	490	490	495	500
FLY BEACH	FIX 3	A	1200	2250	3320	4405	5500	6610	7735
		b_W	520	530	540	545	550	560	565
	6	A	1170	2370	3595	4830	6075	7230	8500
		b_W	590	610	615	620	625	630	640
	8	A	1380	2240	3140	4080	5055	6065	7115
		b_W	420	440	460	480	495	515	535
	10	A	1550	2180	2870	3620	4405	5200	6010
		b_W	300	330	360	390	395	400	410
JOHN'S BEACH	FIX 12	A	625	1750	3150	4670	6190	7710	9230
		b_W	460	620	760	760	760	760	760
	14	A	1200	2070	3060	4100	5180	6280	7380
		b_W	420	500	510	530	550	550	550
Average of 19 sections		A	1230	2190	3240	4400	5550	6700	7980
		b_W	454	505	543	579	592	607	614

SUMMARY OF DATA FORINSTANTANEOUS WATER SURFACE PROFILE

Geodetic water level at Bridge July 26, 1964	2:00 p.m.	begin	2108.85
	6:00 p.m.	end	<u>2108.85</u>
		change	0.00

<u>Section</u>		g.w.l. at <u>July 26 p.m.</u>
Gopher Beach	1	2108.17
	2	8.25
	3	8.27
	4	8.29
	5	8.40
	6	8.47
	7	8.54
Bar Beach	8	9.08
	9	8.69
	10	8.82
	11	8.93
Bridge		8.85
Alfalpa Beach	15	8.98
	17	9.03
	18	9.43
	19	9.47
	20	9.68
"X" Beach	23	10.12
	X	10.10
Thorn Beach	1	10.17
	2	10.35
	3	10.44
	4	10.42
	5	10.45

		<u>g.w.l. at July 27 a.m.</u>	<u>Adjustment</u>	
Thorn Beach	7	2110.76	+ 0.05	10.81
Fly Beach	2	10.97	"	11.02
	3	11.40	"	11.45
	4	11.21	"	11.26
	5	11.35	"	11.40
	6	11.51	"	11.56
	7	11.76	"	11.81
	10	11.72	"	11.77
John's Beach	13	12.57	"	12.62
	14	12.45	"	12.50
	15	12.48	"	12.53

g.w.l. at Bridge July 27, 1964	8:00 a.m.	begin	2108.80
	11:00	end	<u>2108.80</u>
		change	0.00

Change from July 26 p.m. - 0.05' lower.

TABLE 3.7

SIZE ANALYSES OF BED MATERIAL SAMPLES ALONG DEEP WATER CHANNEL

SAMPLING LOCATION		PER CENT FINER THAN - BY WEIGHT PASSING									
		SIEVE SIZE									
FL ¹	SL ²	#200	#100	#60	#40	#20	#10	#4	3/8"	3/4"	
Gopher Beach	1	2	0.3	1.4	10.2	48.3	94.2	98.2	99.5	100.0	
	1	3	0.4	3.2	19.5	81.6	96.0	98.2	98.8	100.0	
	3	2	0.2	7.5	44.9	89.6	96.7	98.9	99.7	100.0	
	5	1	0.6	3.3	17.3	53.6	98.0	99.8	100.0	100.0	
	5	2	0.4	3.0	14.4	76.0	92.5	96.6	98.8	100.0	
Bar Beach	9	3	0.2	2.4	20.8	64.5	92.5	98.3	99.7	100.0	
Alfalfa Beach	14	3	0.3	1.6	10.1	63.1	92.4	97.5	99.2	100.0	
	14	4	0.9	1.4	6.5	31.3	56.7	72.0	88.0	99.9	
	19	3	0.2	6.4	26.2	90.4	97.5	99.0	99.7	100.0	
	21	1	1.3	4.3	17.0	74.9	94.0	98.0	99.4	100.0	
	21	3	1.2	14.3	77.9	98.9	99.8	100.0	100.0	100.0	
"X" Beach	X	1	0.6	1.1	5.8	28.0	76.3	88.8	96.2	100.0	
	X	3	0.2	8.0	35.0	89.0	96.7	99.0	99.7	100.0	
Thorn Beach	3	2	0.2	1.8	9.3	49.6	94.0	98.5	99.5	100.0	
John's Beach	12	5	0.2	1.5	9.6	43.9	88.0	96.1	98.5	100.0	
	15	5	0.2	4.5	21.0	66.2	94.8	98.3	99.6	100.0	
Total of 16 samples			7.4	65.7	345.5	1048.9	1460.1	1537.2	1576.3	1599.9	
Mean			0.46	4.1	21.6	65.5	91.3	96.1	98.5	100.0	

¹ FL = fix line² SL = sailing line

TABLE 3.8
SIZE ANALYSES OF BED MATERIAL SAMPLES IN SHALLOW WATER

SAMPLING LOCATION		PER CENT FINER THAN - BY WEIGHT PASSING SIEVE SIZE								
FL ¹	SL ²	#200	#100	#60	#40	#20	#10	#4	3/8"	3/4"
Gopher Beach	1	0.4	1.4	13.2	53.6	77.7	87.1	91.2	92.3	100.0
	3	0.8	6.9	46.1	93.9	98.0	98.9	99.6	100.0	100.0
	5	0.2	23.9	91.3	99.8	100.0	100.0	100.0	100.0	100.0
Bar Beach	9	0.8	2.3	14.2	53.4	83.4	91.9	96.6	98.7	99.5
Alfalfa Beach	14	0.4	1.2	7.3	19.3	37.3	60.5	80.8	94.4	99.1
	19	0.5	0.9	6.0	32.0	68.8	85.5	91.4	95.8	99.0
"X" Beach	X	1.3	7.4	34.0	93.1	98.6	99.7	99.9	100.0	100.0
Thorn Beach	3	15.9	20.5	27.8	40.1	79.5	90.8	93.3	95.1	98.0
	3	0.3	5.0	27.3	83.6	94.9	98.4	99.5	100.0	100.0
Fly Beach	4	0.4	0.6	2.3	16.8	61.1	79.4	93.5	96.0	100.0
	4	0.4	3.8	15.5	75.1	92.9	97.1	99.2	99.8	100.0
	4	0.5	1.8	10.6	71.3	95.0	97.9	99.3	100.0	100.0
John's Beach	12	0.3	2.4	18.8	87.9	97.0	99.1	99.8	100.0	100.0
	12	0.5	3.3	27.2	84.6	96.1	98.9	99.9	100.0	100.0
	15	9.3	24.1	39.8	84.2	98.3	99.6	99.9	100.0	100.0
	15	0.9	6.7	31.2	77.9	94.6	97.9	99.2	99.9	100.0
Total of 16 samples		33.9	112.2	412.6	1066.6	1373.2	1482.7	1543.1	1572.0	1595.6
Mean		2.1	7.0	25.8	66.7	85.8	92.7	96.5	98.2	99.6

¹ FL = fix line

² SL = sailing line

T A B L E 3.9

S I Z E A N A L Y S E S O F B A N K M A T E R I A L S A M P L E S

SAMPLING LOCATION		PERCENT FINER THAN - BY WEIGHT													
		.001 mm	.005	.01	.02	.04mm	#200	#100	#60	#40	#20	#10	#4	3/8"	3/4"
GOPHER BEACH	FIX 1	Left Bank	12.0	20.0	25.0	36.0	52.0	75.7	95.6	99.3	99.8	100.0	100.0	100.0	100.0
	3	Right Bank	15.0	20.0	26.0	38.0	59.0	85.2	95.9	99.1	99.6	100.0	100.0	100.0	100.0
	3	Right Bank	17.0	22.0	26.0	33.0	43.0	60.4	73.5	78.8	81.2	82.4	83.7	86.0	88.4
	5	Right Bank	17.0	22.0	26.0	34.0	46.0	64.0	78.5	87.3	93.1	95.6	97.0	97.7	98.1
	5	Right Bank	6.0	12.0	14.0	18.0	29.0	34.1	67.1	98.9	99.7	99.8	99.9	100.0	100.0
BAR BEACH	9	Left Bank	7.0	10.0	12.0	15.0	20.0	29.8	65.7	96.4	99.5	99.9	100.0	100.0	100.0
	9	Left Bank	5.0	11.0	14.0	17.0	23.0	36.6	65.9	91.8	99.1	99.7	100.0	100.0	100.0
ALFALFA BEACH	14	Left Bank	21.0	29.0	35.0	44.0	57.0	81.5	97.3	99.3	99.8	99.9	100.0	100.0	100.0
	19	Left Bank	20.0	28.0	36.0	49.0	67.0	87.0	98.7	99.6	99.7	99.8	100.0	100.0	100.0
	19	Left Bank	30.0	50.0	59.0	66.0	71.0	89.9	96.9	99.0	99.7	99.9	99.9	100.0	100.0
	21	Left Bank	20.0	36.0	44.0	53.0	63.0	83.2	91.6	96.3	99.1	99.8	100.0	100.0	100.0
	21	Left Bank	5.0	10.0	13.0	16.0	19.0	23.0	37.3	45.1	51.9	55.8	60.3	68.4	83.3
X BEACH	X	Right Bank	6.0	10.0	13.0	17.0	24.0	45.1	81.4	96.0	99.6	99.9	100.0	100.0	100.0
THORN BEACH	3	Right Bank	5.0	10.0	14.0	19.0	29.0	50.5	90.9	99.4	99.8	100.0	100.0	100.0	100.0
FLY BEACH	4	Right Bank	15.0	27.0	41.0	57.0	73.0	87.5	92.4	94.9	96.1	96.3	96.6	97.2	98.3
	10	Right Bank	24.0	31.0	37.0	45.0	56.0	69.8	77.7	82.4	86.7	90.8	94.8	95.6	97.0
	10	Left Bank	5.0	8.0	9.0	12.0	17.0	34.4	80.2	90.2	96.4	100.0	100.0	100.0	100.0
JOHN'S BEACH	12	Left Bank	5.0	11.0	14.0	19.0	27.0	32.3	63.2	98.5	99.7	99.9	100.0	100.0	100.0
	15	Left Bank	8.0	15.0	20.0	29.0	42.0	61.8	80.1	95.3	98.4	100.0	100.0	100.0	100.0
Total of 19 samples			243.0	382.0	478.0	617.0	817.0	1131.8	1529.9	1747.6	1798.9	1819.3	1832.2	1844.8	1865.1
MEAN			12.8	20.5	25.8	32.5	43.0	59.6	80.5	92.0	94.6	95.7	96.4	97.4	98.1

CHAPTER IV

DISCUSSION OF BED CHANGES AND BED FORMS

In the following chapter, the principal topics are discussed generally in sections 4.1 to 4.4, before proceeding to detailed consideration of the field data in sections 4.5 and 4.6.

4.1 Alternations of Scour and Fill

Bed alternation by scour and fill (or "bed instability") has been studied by various methods such as

- i) observation and photography in laboratory flumes;
- ii) interpretation of unstable stage-discharge relations and variations of cross-sectional shape (Lane and Borland 1954, Simons and Richardson 1962);
- iii) field measurement by repeated cross-sectional soundings, probing with steel rods, burying plastic ribbons, placing log chains (Colby 1964) and by sonic sounding (Neill 1965);
- iv) interpretation of log-log relations of width, depth, velocity and suspended sediment load to discharge rate (Leopold and Maddock 1953);

A comprehensive discussion of methods and data for sand-bed streams is given by Colby (1964).

By interpreting the resulting data, attempts have been made to determine the limits of maximum bed scour, to explain the shifting nature of alluvial channels and to gain insight into sediment transport phenomena.

Such methods are immediately handicapped by the difficulty of using limited data for one point or section to interpret an extremely complicated three-dimensional channel deformation varying with time under conditions of unsteady flow.

Apart from a report by Pretious and Blench (1950) on the Fraser River, the paper by Carey and Keller (1957) on the Mississippi, and Neill's paper (1965) on the Beaver, no other records were found of field studies undertaken with the primary intent of acquiring basic quantitative information on scour and fill by sonic sounding. In the study reported herein, attempts were made to detect by repeated longitudinal sonic soundings along controlled sailing lines the actual nature of bed activity, the magnitude of bed alternation and also some quantitative indications of redistribution of bed materials and rates of bed load transport.

4.2 Bed-forms - General

It is known that scour or fill is generally associated with the transport of bed material and often with some type of more or less regular system of forms shifting along the bed. A study of the literature reveals considerable confusion of terminology. Bed forms have been classified into ripples, dunes and bars; into dunes, waves and super-waves; into micro-, meso-, and macro-forms; etc. The definitions and the relationships between these classifications are obscure, but there seems to be a common recognition of perhaps three orders of magnitude. Observations made in the course of this study tend to support a three-part classification. The sonic soundings detect two categories: firstly "macro-forms", associated with the gross channel geometry, having a wavelength of one to

two channel widths or so, and secondly "meso-forms", the most prominent feature of the sonic charts (FIGURES 3.4 to 3.12) with a wavelength of the order of 1% to 10% of the channel width. "Micro-forms" not detectable on the charts were observed at times in the form of small ripples on bars in clear shallow water.

Attempts have been made to relate bed form types to Froude number or other hydraulic parameters (Pretious and Blench 1950; Simons and Richardson 1963; Znamenskaya 1963). Efforts are made in the present study to discover if there is any correlation between form dimensions and flow characteristics, and to estimate the bed transport rates by considering rates of downstream migration of forms. The two categories of form detectable on the sounding charts will be referred to as macro- and meso-forms, but it is not intended to imply that these terms are standardized in any way.

4.3 Macro-forms (or bars)

Macro-forms may be classified into two or more types. Those most frequently referred to are (i) point or side bars, which are depositional forms occurring on the insides of bends, are associated with channel shift, and are more or less attached to the bank, and (ii) diagonal bars, which are large-scale dune-like forms occurring at crossings where the stream flow switches from one bank to the other. Diagonal bars appear to increase their activity with rise in stage and to be associated with crosswise transport of bed material. Reference has also been made to bars that occur in the middle of the channel but are neither diagonal nor attached to the banks. These will be referred to herein as "midstream bars".

On the river-bed profile as plotted in FIGURE 3.14 one may notice

the regular occurrence of large humps 8 to 10 feet high and 600 to 1400 feet long, that is, of a wavelength equal to once or twice the river width. They are probably related to the pattern of bars visible at low stage on the airphoto (FIGURE 1.2), some of which might be classified as diagonal bars and some as midstream bars. Sonic soundings taken along the thalweg for 150 miles of the river show a similar pattern throughout (Neill and others, 1965). It is clear, as will be shown, that these bars change fairly rapidly at moderate stages and are associated with bed-load transport, but whether there is a systematic downstream migration of forms is uncertain. Large forms travelling downstream in the Mississippi River have been referred to as "super-waves" by Carey and Keller (1957), and Pretious and Blench (1950) have described similar phenomena in the Fraser River.

The pattern of channel bars formed at higher stages probably determines the low-stage flow pattern of sub-meandering and braiding. Some of the midstream bars appear to grow and be stabilized as relatively permanent islands around which the main channel splits. There are no stable islands within the study length at the present time, but they occur farther up- and down-stream.

4.4. Meso- and Micro-forms (or dunes and ripples)

Water flowing over a deformable boundary, such as a bed of cohesionless sand, usually generates a system of wave-forms of more or less regular frequency on the bed, once the bed material begins to move appreciably. They may remain stationary or move with or against the current, depending on hydraulic conditions. Under conditions of gradually changing discharge, as for instance during the passage of a flood wave in a river, changes in wave shape, size and frequency occur and are detectable, as will

be shown. Such forms, which are of much smaller wavelength and amplitude than the macro-forms discussed in 4.2 above, are known to affect the resistance to flow by their shape and frequency, and sediment transport by their rate of migration.

Gilbert and Murphy (1914) made the first extensive and systematic study of sand wave movement under controlled laboratory conditions.¹ They recognized the bed movement as occurring in three distinct modes of transport, which they classified as

- i) tranquil (sub-critical) flow, with dunes moving downstream;
- ii) smooth (sheet, or transitional) flow, with a plane bed;
- iii) rapid (super-critical) flow, with anti-dunes moving upstream.

Subsequent field and laboratory observations by others have produced refinements to the early Gilbert and Murphy observations. Some recent notions are given by Simons and Richardson (1963), who recognize 8 separate bed patterns within the three modes of transport. A recent Russian classification (Znamenskaya 1963) in general runs parallel to theirs, except that it recognizes only 6 patterns. TABLE 4.1 summarizes and compares those three classifications. One important feature of the Russian viewpoint, that seems to have received little attention in American literature, concerns the transformation of short sand-wave forms into longer ones. In describing bed behaviour in the transitional zone, Znamenskaya states

"Other conditions being equal, with an increase in the bed load discharge, in this region the dunes change their length in jumps, about doubling it each time. In such a way, they are rapidly flattened out and approach the smooth bottom phase at an intensive transport of sediment. In the body of such dunes, consisting of very fine sand, secondary dunes never occur."

¹ The Gilbert-Murphy experiments remain to the present time as the most complete range of flume data available on bed transport. They used 8 sizes of uniformly graded bed materials ranging from 0.3 to 7.0 mm.

Pretious and Blench (1950) in their Fraser River report have observed wave groups and wave trains, and by counting wave tips on sonic sounding charts have noted systematic changes in dune length and frequency with changes in discharge. FIGURE 4.1 plots the results of their observations as discharge and wavelength against time. This diagram shows wavelength increasing more or less systematically with rising discharge (which is in accord with the above-quoted laboratory observations of Znamenskaya) and decreasing with falling discharge. It is suggested that the mechanism of change in wavelength is probably a transformation of short waves into longer ones as mentioned by Znamenskaya and as illustrated in the following sketch.

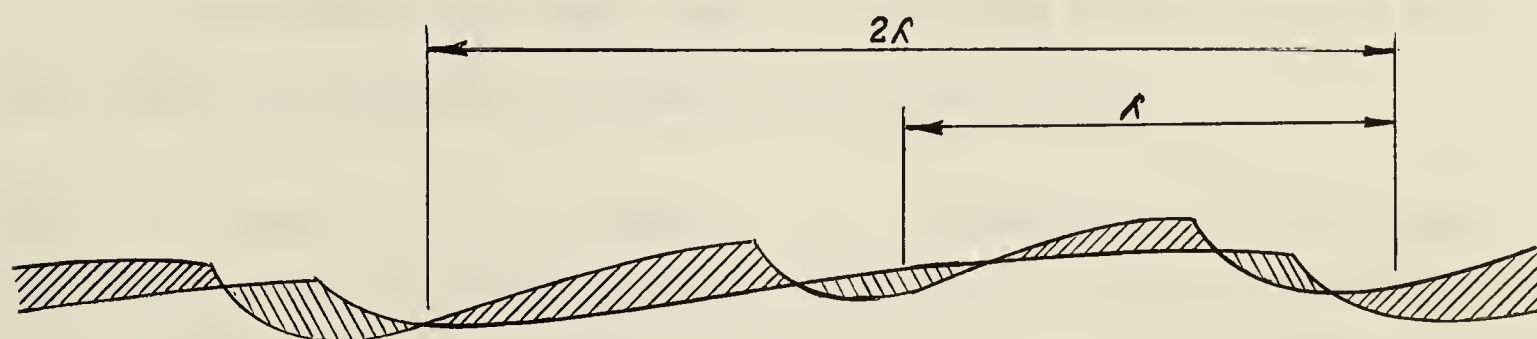


Illustration of
two small sand waves transforming
by erosion and deposition into a larger
wave of double wave length.

A controversial point is whether the dunes observed in laboratory channels are analogous to the much larger dunes observed in nature, or rather to the smaller ripples of natural channels. Since the present study is confined to field phenomena, the dunes observed on the sonic charts are classified as meso-forms. This avoids the question of whether to classify laboratory dunes as meso- or micro-forms.

4.5 Analysis of Field Data on General Bed Topography, Scour and Fill, and Macro-forms

It is convenient to consider firstly a two-dimensional picture of general bed behaviour along the thalweg, or deepest part of the channel. A contour map was prepared from the longitudinal soundings and cross-sections, showing the pattern of depths over the study length at the time of Tour 3 (July 3-8 approximately). An approximate thalweg line was drawn on the map by connecting suitable portions of the nearest longitudinal sailing lines, as shown on Map no. 1 (back cover). FIGURE 4.2 shows longitudinal bed profiles along this approximate thalweg line for the three successive tours. These are plotted as depths below the sloping reference stage, with the vertical scale exaggerated 100 times.

In general, the river stage and discharge pattern between the three tours as illustrated in FIGURE 4.2 was as follows:

Tour no.	Date	Stage	Change	Discharge c.f.s.
1	June 11/12	rs + 2.9 to 2.3		7,400 - 5,700
2	June 24/25	rs + 4.4 to 3.8	rise \pm 1.5'	10,700 - 9,400
3	July 3/4	rs + 1.1	fall \pm 3.0'	4,000

Some important features of FIGURE 4.2 are as follows:

1. It is evident that with even the small changes in stage that occurred, considerable changes took place in the bed along the thalweg. The maximum single change in depth recorded occurred between Tours 1 and 2 downstream of the old bridge piers, and amounted to 3.5 feet of scour, with a rise in stage of approximately 2 feet.

2. On the average, the thalweg scoured slightly between Tours 1 and 2, and re-filled partly between Tours 2 and 3. This is demonstrated by TABLE 4.2, which shows a calculation of average elevations along the thalweg, divided into five sub-lengths. These average changes, however, are very small compared to local changes.
3. Between any two successive tours, lengths of scour along the thalweg in general alternate with lengths of fill. The average distance between nodal or reversal points is approximately 1000 ft. This spacing corresponds roughly with the wavelength of major undulations illustrated in FIGURE 3.14 and referred to in section 4.3.
4. There is little consistency from point to point in the sequence of scour and fill corresponding to the three tours. At some points scour between Tours 1 and 2 was followed by fill between Tours 2 and 3, at others by more scour. At other points fill was followed by more fill or by scour.
5. The greatest vertical changes occurred near bends in the channel, and in the vicinity of the old bridge foundations, which cause a substantial reduction in net channel width. Changes near the Highway 36 bridge were no greater than those at many other points.

Simultaneously with those changes in the longitudinal direction, changes also took place in the transverse direction. FIGURE 4.3 shows transverse bed profiles for the three Tours plotted on a number of selected cross-sections. It can be seen that scour and fill in the thalweg was often accompanied by opposite effects at shallower points on the sections.

To study the overall volumetric balance of the bed, a large number of closely-spaced (20' intervals) spot depths, taken from the sonic charts, was surveyed over two areas of channel, the first approximately 2100' long x 300' wide at Gopher Beach, and the second approximately 1850' long x 500' wide at Alfalfa Beach, as shown on Map no. 1 (back cover). The calculations are tabulated in TABLES 4.3 and 4.4. TABLE 4.3 indicates average overall scour of 0.33 feet between Tours 1 and 2, and recovery of 0.26 feet between Tours 2 and 3. TABLE 4.4 indicates practically zero change between Tours 1 and 2, and 0.17 feet scour between Tours 2 and 3. These average changes are very small compared to local changes and indicate little net removal or addition of material over those areas.

4.6 Analysis of Field Data on Meso-forms

The selected longitudinal sonic sounding charts, FIGURES 3.4 to 3.12 inclusive, show a variety of wave-like bed forms ranging widely in both wavelength and amplitude, that changed their forms and dimensions noticeably between successive sounding tours. These changes will be considered for one division of the study length at a time.

Gopher Beach division, FIGURES 3.4 to 3.7. At the time of Tour 1, Sailing Line (1) did not show much recognizable dune pattern, but SLs (2) and (3) showed clear dune forms, with relatively steep downstream faces, of the order of 20 feet wavelength and 1.5 feet amplitude. By the time of Tour 2, the latter had increased noticeably to about 40 feet wavelength x 2 feet amplitude. By Tour 3 these dimensions had decreased to about 20 feet x 1 foot along SL (2) and about 10 feet x 0.5 feet along SL (3).

Tours 2 and 3 along SL (1) show several large forms about 80 feet x 3 feet in size, with a fine pattern superimposed. Between the

tours these large forms more or less retained their shape and position, and it is questionable whether they can be properly classified as dunes. Since similar constant forms did not occur elsewhere, it appears likely that they were associated with local turbulence caused by the old pier foundations just upstream.

Two features of FIGURES 3.4 to 3.6 are worth special mention:

- i) the pattern between cross-sections (1) and (3) on SL (3) at Tour 2, which suggests transformation of the smaller dunes of Tour 1 into larger dunes of approximately double wavelength (as illustrated by the sketch in section 4.4);
- ii) the local scour hole at the upstream end of the old pier foundation on SL (1), Tours 1 and 2 (FIGURE 3.4), approximately 5 feet deep below general bed level in the vicinity.

Bar Beach division, FIGURES 3.7 to 3.9. These charts show rather similar changes. On SL (1), portions of bed that showed no detectable wave pattern during Tour 1 showed recognizable dunes during Tour 2 and reverted to a finer pattern during Tour 3. Along SL (2) the sequence is similar, but the scale of the pattern is slightly greater. SL (3), which is in midstream and approximately along the thalweg at this point, is particularly interesting. Between cross-sections (6) and (9), where the pattern was quite fine during Tour 1, large forms up to 80 feet x 3 feet developed by the time of Tour 2, and farther upstream even larger forms appeared. By Tour 3, this pattern had disappeared, and the maximum form dimensions were approximately 15 feet x 1 foot.

Alfalfa Beach division, FIGURES 3.10 and 3.11. Only SLs (3) and (4) are reproduced. The charts show first of all a curious anomaly. This is

that the early test run soundings of May 27, when discharge was only 2600 cfs, show a coarser pattern than those of Tour 1, when the discharge was 6150 cfs. Reference to the river hydrograph, FIGURE 3.2, may suggest an explanation. A crest of approximately 14,000 cfs had occurred on May 10, followed by a steady recession to May 27, after which there was a fairly steady rise up to the time of Tour 1. It is suggested that the May 27 pattern still showed some lag effects from the previous peak, and that smoothing continued thereafter, whereas by Tour 1 it had not yet adjusted to the new rise.

Another apparent anomaly is seen between Tours 1 and 3, SL (4), where the flow was deepest and fastest (velocity approximately 4.5 ft/sec). Between cross-sections (18) and (19), a moderate dune pattern at Tour 1 disappeared by the time of Tour 2, leaving a relatively smooth bed with very flat undulations. Tour 3 shows a fine pattern again. No other example of this kind was obtained in the course of the study. With reference to the bed regime classification of Simons and Richardson (1963), as quoted in section 4.2, this may be an example of Type (d) called "washed-out dunes or transition".

The sequence on SL (3) Tour 1 to 2 to 3, shows a very clear example of the effect of changing flow on bed pattern. Between cross-sections (18) and (20) both Tours 1 and 3 show either small dunes of 10 feet x 1 foot or no detectable pattern. Tour 2 shows large dunes ranging from 20 feet x 1.5 feet to 40 feet x 3 feet.

X Beach division, FIGURE 3.12. The single chart reproduced for SL (3) at Tour 3 shows a good example of regularity of form along the middle of a relatively straight reach, and possible indications of large dunes transforming into smaller ones of half wavelength. (The chart represents a falling stage.)

The foregoing observations point to the following conclusions:

- i) meso-form or dune wavelengths and amplitudes in general increase with rising stage and decrease with falling stage, but this general conclusion is not necessarily true at every point on the channel bed;
- ii) there is probably a considerable time lag between change in stage and corresponding change in bed pattern, on both rising and falling stages;
- iii) there is strong evidence of washing-out of dunes to a "transitional" type of bed in at least one reach of the thalweg under the highest flow observed.
- iv) the first anomaly discussed under Alfalfa Beach division above suggests that bed activity is proceeding at discharges of only 2000 to 3000 cfs, at least in some places;
- v) there is some indication that dune dimensions may transform by doubling or halving of wavelengths.

4.7 Observations of Local Scour

Efforts were made to obtain data on local scour at three places: the present Highway 36 bridge, the old pier foundations, the sharp bend near the upstream end of the study length (Fly Beach division, cross-section 10).

In several soundings by boat around the piers of the present bridge, no evidence was obtained of any remarkable local scour around the foundations that might be ascribed mainly to the effect of the piers. Soundings made by boom off the bridge near the crest of June 24 ($Q \approx 11,000$ cfs) indicated a maximum flow depth of approximately 13 feet at the nose of the north pier (in the main current), where the general depth was around 10 to 11 feet, thus suggesting 2 to 3 feet of local scour. As the width of the piers at bed level

is only 3 feet, the piers are aligned with the flow, and there are no surrounding obstructions, these findings are in accord with present opinion regarding local pier scour, and show that the design of the piers is good for minimizing local scour.

Numerous soundings were made around the old pier foundations at cross-section (5), Gopher Beach division. These foundations are rock-filled timber cribs approximately 10 feet wide x 50 feet long, are approximately parallel to the banks, project approximately 10 feet above the bed (see FIGURE 3.13), and appear to be partly surrounded by rip-rap. The southernmost foundation, which is in the main current, appears to have a more or less permanent local scour hole around its nose, extending to 5 to 6 feet below the general bed level. There are also indications of scour occurring between the foundations at higher stages (see FIGURE 4.2).

FIGURES 4.4 (a), (b) and (c) show bed contours, drawn as lines of equal depth below reference stage, for the three successive tours in the vicinity of the sharp bend. FIGURE 4.5 shows successive longitudinal bed profiles at the same location, along SL (2). The contours of FIGURES 4.4 refer to the median profile lines of FIGURE 4.5, which represent the middle of the dune envelope indicated by the sonic charts. The maximum depth observed at Tour 2 ($Q \div 9400$ cfs) was 12 feet below reference stage, or approximately 16 feet below water surface. The average depths along the thalweg for the entire study length at this stage was slightly over 8 feet below water surface, so that depth at the sharp bend was approximately twice the average along the thalweg. A sonic chart showing this deepest hole, on SL (2), Fly Beach division, near cross-section (11), is shown on FIGURE 3.12.

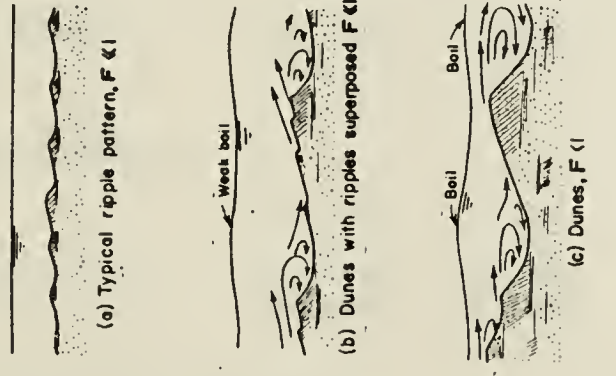
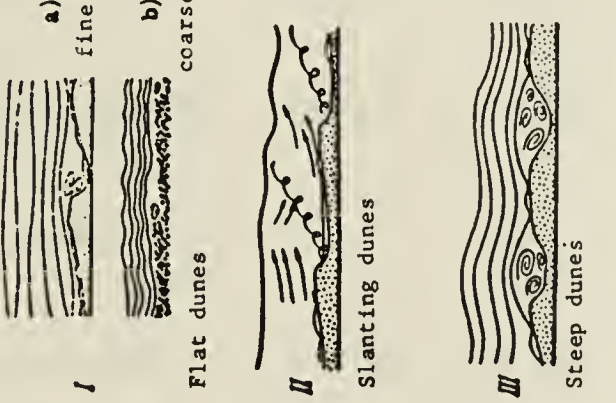
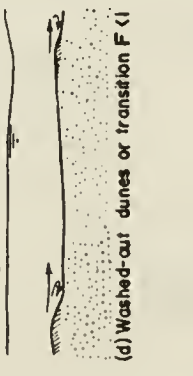
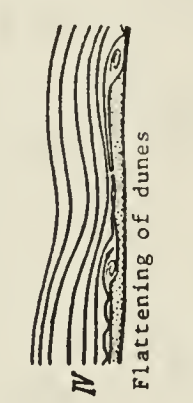
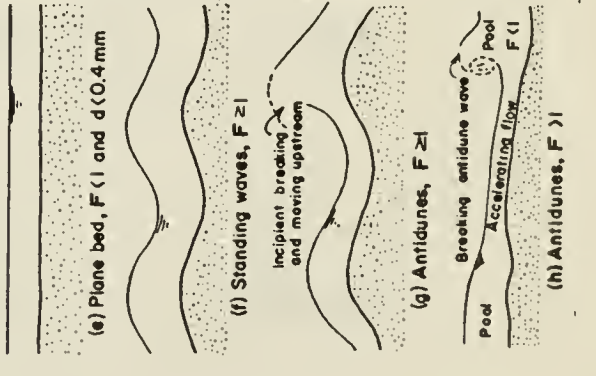
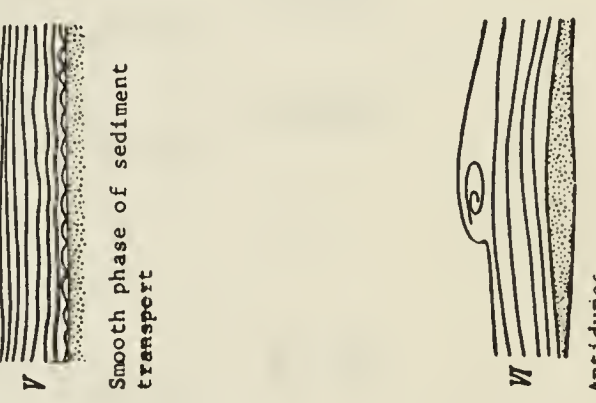
Gilbert-Murphy U.S.G.S., 1914	Simons and Richardson, U.S.G.S. (1963)	Znamenskaya, U.S.S.R. (1963)	REMARKS
<p>TRANQUIL OR SUB-CRITICAL FLOW</p> <p>Dunes moving with the current</p> <p>$F < 1$</p>	<p>LOWER FLOW REGIME</p>  <p>(a) Typical ripple pattern, $F < 1$</p> <p>(b) Dunes with ripples superposed $F < 1$</p> <p>(c) Dunes, $F < 1$</p> <p>(d) Washed-out dunes or transition $F < 1$</p>	 <p>I fine</p> <p>II coarse</p> <p>III Flat dunes</p> <p>IV Slanting dunes</p> <p>V Steep dunes</p> <p>VI Flattening of dunes</p>	<p>The bed configuration may be ripples or dunes.</p> <p>The resistance to flow is relatively large.</p> <p>The bed material load is relatively small and moves close to the bed over the backs of ripples or dunes and at the crest some of the bed load avalanches down the face, causing the advance of the ripple or dune form. Some bed material is carried into suspension</p> <p>The bed load is closely related to the velocity of the roughness elements.</p>
<p>SMOOTH OR TRANSITIONAL FLOW</p> <p>Approximately plane bed</p>	<p>TRANSITION</p>  <p>(e) Plane bed, $F < 1$ and $d < 0.4 \text{ mm}$</p>	 <p>V Smooth phase of sediment transport</p>	<p>The bed configuration may range from plane bed to fully developed dunes.</p> <p>There is a discontinuity in resistance to flow and sediment transport relations.</p>
<p>RAPID OR SUPER-CRITICAL FLOW</p> <p>Antidunes moving against the current</p> <p>$F > 1$</p>	<p>UPPER FLOW REGIME</p>  <p>(f) Standing waves, $F > 1$</p> <p>(g) Antidunes, $F > 1$</p> <p>(h) Antidunes, $F > 1$</p>	 <p>VI Antidunes</p>	<p>The bed configuration may be plane, standing waves or antidunes.</p> <p>The resistance to flow is relatively small.</p> <p>The bed material transport is relatively large and is closely related to the velocity of individual grains.</p>

TABLE 4.1 - PUBLISHED CLASSIFICATIONS OF ALLUVIAL BED CONFIGURATIONS

TABLE 4.2

AVERAGE BED ELEVATIONS ALONG THALWEG

Planimeter areas are taken from FIGURE 4.2 between rs + 0 and bed profile.
 $1 \text{ in}^2 = 400 \text{ ft}^2$

Division	Length ft.	Tour 1 area in ² d-ft.		Tour 2 area in ² d-ft.		Tour 3 area in ² d-ft.	
Gopher Beach	1,715	17.78	4.15	22.47	5.25	20.14	4.70
Bar Beach	2,225	22.28	4.10	24.47	4.40	22.85	4.10
Alfalfa Beach	2,015	22.69	4.51	22.89	4.55	23.86	4.75
"X" Beach	-	-	-	-	-	-	-
Thorn Beach	3,230	35.46	4.40	39.31	4.86	41.39	5.11
Fly Beach	3,520	31.80	3.62	39.00	4.44	35.83	4.06
John's Beach	-	-	-	-	-	-	-
Totals	<u>12,705</u>	<u>130.57</u>		<u>148.14</u>		<u>144.07</u>	
Average Bed Elevation along Thalweg, as depth below reference stage			4.10		4.66		4.54

TABLE 4.3

VOLUMETRIC BALANCE - GOPHER BEACH DIVISION

Spot depth readings taken from sonic charts at 20' intervals - Average depth is with respect to rs+0.

	<u>TOUR 1</u>	<u>TOUR 2</u>	<u>TOUR 3</u>
Stage	rs + 2.9	rs + 4.4	rs + 1.1
Discharge - cfs.	7,400	10,700	4,000
Sum of 106 spots SL 1	461.0	494.8	452.2
Average depth - ft.	4.36	4.66	4.25
Sum of 106 spots SL 2	437.5	471.8	480.4
Average depth - ft.	4.13	4.45	4.54
Sum of 106 spots SL 3	350.6	390.0	339.4
Average depth - ft.	3.31	3.68	3.20
Sum of 318 spots	<u>1,249.1</u>	<u>1,356.6</u>	<u>1,272.0</u>
Average depth - ft. below rs	3.93	4.26	4.00

TABLE 4.4

VOLUMETRIC BALANCE - ALFALFA BEACH DIVISION

Spot depth readings taken from sonic charts at 20' intervals.

	<u>TOUR 1</u>	<u>TOUR 2</u>	<u>TOUR 3</u>
Stage			
Discharge - cfs.			
Sum of 92 points SL 1	208.0	184.2	168.6
Average depth - ft.	2.26	2.0	1.83
Sum of 92 points SL 2	91.9	96.4	108.4
Average depth - ft.	1.00	1.05	1.18
Sum of 92 points SL 3	289.7	339.5	389.2
Average depth - ft.	3.05	3.70	4.23
Sum of 92 points SL 4	394.8	385.6	387.6
Average depth - ft.	4.30	4.19	4.21
Sum of 368 points	<u>984.4</u>	<u>1,005.7</u>	<u>1,053.6</u>
Average depth - ft. below rs	2.67	2.70	2.87

CHAPTER V

REGIME ANALYSIS

5.1 Regime and other equations

It has long been observed in nature that a water bearing channel in alluvium, whether an artificial canal or a natural river, creates by a process of self-formation a characteristic channel geometry. There are three fundamental factors that affect this geometry

- i) the discharge
- ii) the nature of the boundary, i.e. mobile or rigid
- iii) the nature of the fluid, i.e. the water-sediment complex.

Regime theory, with its equations and attendant notions attempts to explain and predict the self-formation of such channels. To accomplish this, three equations have been developed to predict, in terms of average values of the fundamental factors, the three self-adjusting geometric channel variables, width, depth and slope. The regime method is an empirical one and is likely to remain so in the future.

The notions of regime theory were evolved by the engineers operating the Indian canal systems, (Blench 1957). In 1895 Kennedy related velocity and depth in the form $V = cd^n$ giving $c = 0.84$ and $n = 0.64$. In 1919 Lindley introduced a velocity-width relation of the same form and gave his two equations as $V = 0.95d^{0.57}$ and $V = 0.57b^{0.355}$. Ten years later Lacey effectively modified the indices and introduced a third equation which included the slope and a silt factor. By 1955 work by Blench, King and Erb had resulted in Blench proposing generalizations of the Lacey equations which could be regarded as splitting the silt factor into components related to bed and side, and introducing bed load intensity. Although regime theory was developed from field data

of full scale canals running under fairly steady conditions and known to have fairly stable channels it is believed that the notions remain valid and the equations can be applied within practical limits to rivers running in alluvium. In their present form as used herein, the regime equations are:

$$\text{Bed Factor} = F_b = V^2/d \quad 5.1$$

$$\text{Side Factor} = F_s = V^3/b \quad 5.2$$

$$V^2/dgS = 3.63 (1 + aC) (Vb/\nu)^{1/4} \quad 5.3$$

which after rearrangement, and with $a = 1/233$, predict the average channel geometry for straight alignment and active bed as:

$$\text{Width} = b = \sqrt{Q \frac{F_b}{F_s}} \quad 5.4$$

$$\text{Depth} = d = \sqrt[3]{Q \frac{F_s}{F_b^2}} \quad 5.5$$

$$\text{Slope} = S = \frac{F_b^{5/6} F_s^{1/12}}{(3.63g/\nu^{1/4})(1 + C/233) Q^{1/6}} \quad 5.6$$

For application to rivers, equation 5.6 is qualified to the form

$$S = (klm) \left[\frac{F_{bo}^{11/12}}{\frac{3.63g}{\nu^{1/4}} b^{1/6} Q^{1/12}} f^{111}(C) \right] \quad 5.7$$

where (klm) is at present, a subjectively determined factor providing mainly for meandering and partly for departure from perfect canal conditions. Indications are that k , which covers meandering, ranges from 1.0 for canals to about 2.5 for typical alluvial rivers.

For use below, the conventional Manning n and Darcy-Weisbach friction factor f are given by equations 5.8 and 5.9:

$$n = 1.486 d^{2/3} S^{1/2}/V \quad 5.8$$

$$f = 8gdS/V^2 \quad 5.9$$

5.2 Regime and Hydraulic Variable Computations

The average data presented in Chapter III have been applied to the basic equations 5.1 and 5.2 for evaluation of the parameters F_b and F_s , to equation 5.6 for comparison of computed and observed slopes, to equation 5.7 for estimation of bed load charge and to equations 5.8 and 5.9 for evaluation of n and f . The results are tabulated in TABLE 5.1 and plotted on FIGURES 5.1 and 5.2. Some relevant comments now follow.

5.3 Discussion of Regime Aspects

FIGURE 5.1 shows F_b to have a fairly constant value of 1.51 above stage $rs + 1$, $Q = 3,700$ cfs. According to the empirical rule for zero bed factor, the threshold of bed activity along the control reach is estimated to occur when $F_{bo} = 1.9 \sqrt{D_{mm}} = 1.11$. If the dotted extrapolation of FIGURE 5.1 be permitted then detectable bed activity should begin at something like stage $rs - 3$, $d \approx 1$ foot and $Q \approx 400$ to 500 cfs. At the lowest stage of field observations, stage $rs + 0$ and $Q = 2350$ cfs, the bed factor is 1.35 and sufficiently beyond the threshold to indicate that the bed should be in a mild state of dune activity. The sonic charts taken at low water on May 26 and 27, FIGURES 3.9, 3.10 and 3.11, show that the bed is indeed in a mildly active state with dune size about $1' \times 10'$. By the time of Tour 1, stage $rs + 2.9$, $Q = 7800$ cfs, $F_b = 1.51$, the sonic charts show well developed dune patterns with dunes 3 feet high in the narrow Gopher Beach area and generally 1 to 2 feet high in the remaining wider areas. By the time of Tour 2, stage $rs + 4.4$, $Q = 10,700$ cfs, $F_b = 1.51$, approximately at the flood wave crest, the sonic charts show a considerable increase of bed activity. After the flood wave recession and at the time of Tour 3,

stage $rs + 1.1$, $Q = 4,000$ cfs, $F_b = 1.5$, the bed has lapsed into a mild state of activity with the evidence of Tour 2 mostly erased.

It should be noted that above stage $rs + 1$, $Q = 4,000$, F_b has remained fairly constant at 1.51 while the sonic charts show a decided variation of bed activity. This fact seems contrary to the notion that F_b is the indicator of bed activity. Several possible explanations are offered:

- i) while F_b for the reach remains as a constant average value, it may be the fluctuations of local values, which themselves differ between locations, about this overall average that cause the bed disturbance,
- ii) F_b as a parameter reaches a maximum limiting average value at some critical stage and then ceases to operate,
- iii) some other parameter not accounted for may be operating and/or may come into operation at some critical stage. A highly probable parameter of such kind may be the b/d ratio,
- iv) the bed activity along with F_b may indeed reach a maximum limit at some intermediate stage but not yet evident on the sonic charts due to time lag of bed reformation. It is not possible however to determine this possibility for lack of data above stage $rs + 4.4$. However this explanation seems the least probable since the reasonable expectation would be that, for increasing discharge intensities, the stream's capability to stimulate bed activity would increase.

A digression is now made with regard to the threshold of bed activity by examining some recent laboratory and canal data in terms of Froude number, F and bed-load intensity, C (in parts per 100,000 by weight). The data show the following linear trends (fitted by eye).

Znamenskaya (1963) 1.64' flume, up to $C = 200$	$\frac{b}{d}$
coarse graded sand 0.8 ^o mm	$F = 0.5 + .0028C$ 2.6 to 11.4
fine grade sand 0.18mm	$F = 0.4 + .0023C$ 3.5 to 12.5

Simons and Richardson (1962, 1963) 8' flume - up to $C = 200$	
medium graded sand 0.45 mm	$F = 0.24 + .0027C$ 8 to 42
medium graded sand 0.28 mm	$F = 0.25 + .0027C$ 7.5 to 26.7

Simons and Albertson (1963) canals - up to $C = 50$	
ranging from fine to coarse sands	$F = 0.13 + .0027C$ 5.3 to 24
but mostly medium sizes	

Note should be taken:

- i) of the scale effect on the F intercept at $C=0$ as between, narrow flume, wide flume and full scale canals, i.e. as the size of the flow system increases the threshold of bed activity, in terms of Froude number decreases,
- ii) that the ratio b/d would probably not operate as a parameter except at values lower than say 3 or 4, i.e. wide, deep channels or extremely high stage,
- iii) that the threshold of bed activity in prototype flow with a bed of naturally graded medium sized sand may occur at F as low as 0.13 or $F_{bo} = 0.6$.

According to the results in TABLE 5.1 the predicted regime slope, by equation 5.6 for a straight, neat canal-like channel averages a fairly constant 0.12'/1000'. The measured average slope over the control reach is about 0.268'/1000' or 2.23 times greater and within the expected range of 1.5 to 2.5 for typical rivers. Also, this value may be assessed from the f/g vs. Vb/γ plot, FIGURE 5.2 as:

$$\log f_{\text{river}} - \log f_{\text{canals}} = 0.344 \text{ and}$$

$$f_{\text{river}} = 2.21 f_{\text{canal}}$$

The bed load charge has been computed according to equation 5.7 using a value of $(klm) = 1.3$. This was assessed from FIGURE 5.2, in terms of f vs. $4Vd/\gamma$ diagram as:

$$\log f_{\text{river}} - \log f_{\text{canals}} = 0.122 \text{ or}$$

$$f_{\text{river}}/f_{\text{canals}} = 1.3.$$

The $f'''(C)$ values are taken from charts as given by Blench (1957). The predicted charge ranges from 9 at low stage to 16 at bankfull. For comparison with a river of similar setting the values computed herein are plotted on the FIGURE 5.3. Taken by itself, a computed value of bed charge has little significance except as a relative order of magnitude indication of the severity of bed

activity. For the case of the study length, the bed activity, as observed, was just beyond the threshold of zero bed movement and of a sonically sensible order of magnitude which might be categorized as mild. To become destructively severe would probably require a range of C values 3 or 4 fold greater than those computed and an average F_b for the reach of 2 or 3. According to FIGURE 5.1, such an F_b on a reach-wide basis is unlikely. However on a sub-reach basis such values are entirely possible, as for example along Gopher Beach where F_b is roughly estimated as 2.2 ($F \approx .26$) and bed activity of high order was sonically observed. For purpose of studying channel self-formation, bed load estimates would become more significant if taken together with suspended charge and studied in relation to total load.

In order to compare the study length with other rivers of like kind the Z parameter, Blench (1964), given by the equation

$$Z = b^{1/6} S / F_{bo}^{11/12} \quad 5.10$$

has been computed and set on FIGURE 5.4, the top line of which is representative of typical rivers with detectable bed load charge. The point is noted to fall near this line, suggesting no abnormality from typical regime river behavior, and consistent with the bed activity as sonically observed.

The Manning n as herein computed ranges from .025 at low stage to 0.031 at bankfull. This slight increasing trend is typical of broad channels and according to the analysis given by Blench (1957, page 71). This range of values agrees with ones given by Chow (1959).

The computed value of the Darcy-Weisbach f is of the order 0.045. The plotted points on FIGURE 5.1 and the ones on FIGURE 5.2 in terms of $4Vd/\nu$ are slightly erratic, probably due to fluctuations in the field

data, however a slight decrease in f with rising stage can be imagined as shown by the dotted line. This trend might be expected since the equivalent roughness height, x/d , probably decreases due to a decrease of dune frequency with rising stage, giving the effect of less frictional resistance.

TABLE 5.1

SUMMARY OF REGIME AND HYDRAULIC VARIABLES

Stage	Q	A	b	d	V	F _b	F _s	Sx10 ⁻³	F	Zx10 ⁻³	f _{III} (C)	Cx10 ⁻⁵	q	g _s	n	f	R _d x10 ⁶	f/8	R _b x10 ⁸
rs + 0	2350	1230	454	2.71	1.91	1.35	.015	.126	.205	.68	.190	9	5.18	.028	.0249	.0513	1.70	.00643	.714
+ 2	5600	2190	505	4.34	2.56	1.51	.033	.128	.217	.69	2.07	11	11.1	.075	.0253	.0456	3.65	.00571	1.06
+ 4	9800	3240	543	5.96	3.03	1.54	.051	.124	.218	.70	2.21	12	18.0	.135	.0264	.0448	5.94	.00562	1.35
+ 6	15000	4400	579	7.60	3.41	1.53	.069	.120	.217	.71	2.30	13	25.9	.21	.0277	.0452	8.53	.00564	1.62
+ 8	21000	5550	592	9.37	3.79	1.52	.093	.112	.218	.71	2.38	14	35.5	.31	.0286	.0450	11.7	.00563	1.85
+ 10	28000	6700	607	11.05	4.18	1.58	.12	.113	.221	.71	2.44	15	46.1	.43	.0289	.0436	15.2	.00545	2.09
rs + 12	35000	7980	614	13.00	4.38	1.48	.14	.104	.21	.71	2.50	16	57.0	.57	.0307	.0467	18.7	.00584	2.21

Q from tentative stage-discharge relation, Figure 3.3

A average of 19 cross-sections, Table 3.5

b average of 19 cross-sections, Table 3.5

d = A/b

V = Q/A

F_b = V²/dF_s = V³/bS = F_b^{5/6} F_s^{1/12} / KQ^{1/6} where K = 3.63g/γ^{1/4} = 1975for g = 32.2 ft./sec²ν = 1.215 x 10⁻⁵ ft²/sec. at 60°F

F = V/√gd

Z = b^{1/6} S/F_{bo}^{1/12} where F_{bo} = 1.9√D_{mm} = 1.11 for D_{mm} = 0.34f_{III}(C) = 1975 ZQ^{1/12}/klm where klm = 1.3

C from Blench (1957) Figure 4.1

q = Q/b

g_s = 62.4qCn = 1.486d^{2/3} S^{1/2}/V with S = 0.268'/1000'f = 8gdS/V²R_d = 4Vd/γR_b = Vb/γ

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Effectiveness of Methods

The method of successive sonic sounding used has proved useful for study of bed activity in a sand-bed river. The method might be extended to more detailed and precise study, using both moving and stationary equipment. For instance, surveys might be repeated at 6 to 12 hour intervals over short lengths of a few hundred feet, closely marked, to study rates of movement of forms and sequence of scour, possibly during floods. It might be possible to determine the threshold of incipient bed motion by such a method applied at low stages. In future studies, more attention should be paid to velocity surveys, together with measurements of suspended load and water temperatures. Slope measurement should be more detailed, with attention to variations over short lengths.

The control survey required a disproportionate expenditure of time. Probably a quicker method of establishing horizontal control could be devised.

6.2 Summary of Results

The principal findings may be listed as follows:

- i) With rise and fall of stage macro-deformation of the bed occurs both longitudinally and transversely over at least part of the channel width. This deformation consists of an alternation of scour and fill along and across the channel, and appears to be linked with the presence of large diagonal or midstream bars of the order of one to two channel widths apart. The movements of these bars

were not specially studied, but it might be convenient in future investigations to follow them by a sequence of air photographs at low stages.

- ii) Bed dunes have been observed to grow and shrink in both wavelength and amplitude in harmony with rise and fall in stage. Those detectable on the sonic charts range from 10 feet x 0.5 feet to over 100 feet x 3 to 4 feet in dimensions. Their rate of migration was not determined in this study, but it should be possible to do this by sonic sounding, using a closely spaced control grid and frequently repeated passes over a small area.
- iii) Calculations of volumetric balance show no very significant change in average bed levels over lengths of channel equal to several widths, for the changes in stage observed during the study.
- iv) The maximum scoured depth observed in the channel occurred just downstream of the sharp bend (of approximately 60° deflection angle) near the upstream end of the study length, and was quite localised (FIGURE 3.12). It amounted to 16 feet below water surface, or 8 feet below general bed level in the vicinity. It was also approximately twice the average depth along the thalweg.

The maximum depth observed near the pier foundations of the present Highway 36 bridge was 13 feet, and near the ruined foundations of the old bridge 15-1/2 feet. Both of those were at the noses of the piers.

All the above maximum depths were observed at a stage of approximately 4 feet above reference, and a discharge of approximately 11,000 cfs, which is somewhat less than the median annual peak flow.

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APPENDIX 1

The following is a suggested list of basic data required for scientific analysis of a river, Neill (1964).

1. Map, and air and ground photos. at various stages (particularly flood stages).
2. Flood frequency curve, mean annual discharge, estimated bankfull discharge, typical annual hydrographs.
3. Stage-discharge or depth-discharge curves.
4. Longitudinal profile and typical cross-sections of channel and flood-plain, showing water-levels for key discharges, and change of sections with stage.
5. Average widths, depths, slopes, and meander wavelengths and amplitudes.
6. Sediment size analyses from bed, banks and flood-plain.
7. Suspended and bed-load transport measurements.
8. Sub-soil borings in flood-plain and river-bed, and geological history.
9. Echo-soundings at various stages, showing dimensions of bed-forms and changes with stage.
10. Velocity distributions, water temperatures, ice conditions.
11. Scoured depths at structures and constrictions during high stages.
12. Rates of channel shift and meander sweep, from successive maps or surveys.
13. Evidence of bed degradation or aggradation, as shown by long-term trend of stage-discharge relations.



LOCATION OF STUDY LENGTH
LOWER RED DEER RIVER

Tp. 22, Rg. 14, W4m.
Scale: 1 in. = 3330 ft.

FIGURE 1.1

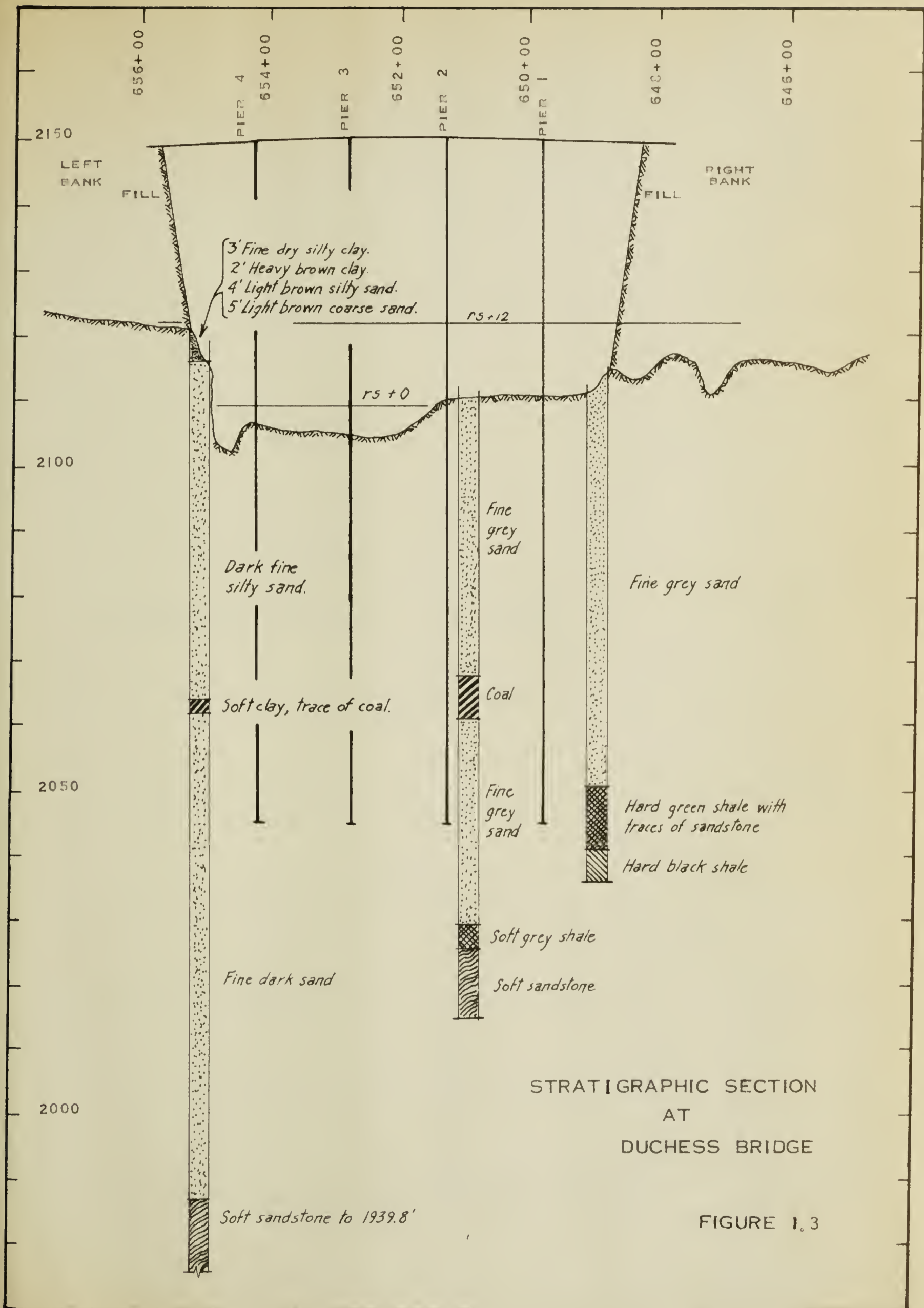
LOWER RED DEER RIVER

AIR PHOTO OF STUDY LENGTH

Approximate Scale: 1 in. = 1050 ft.

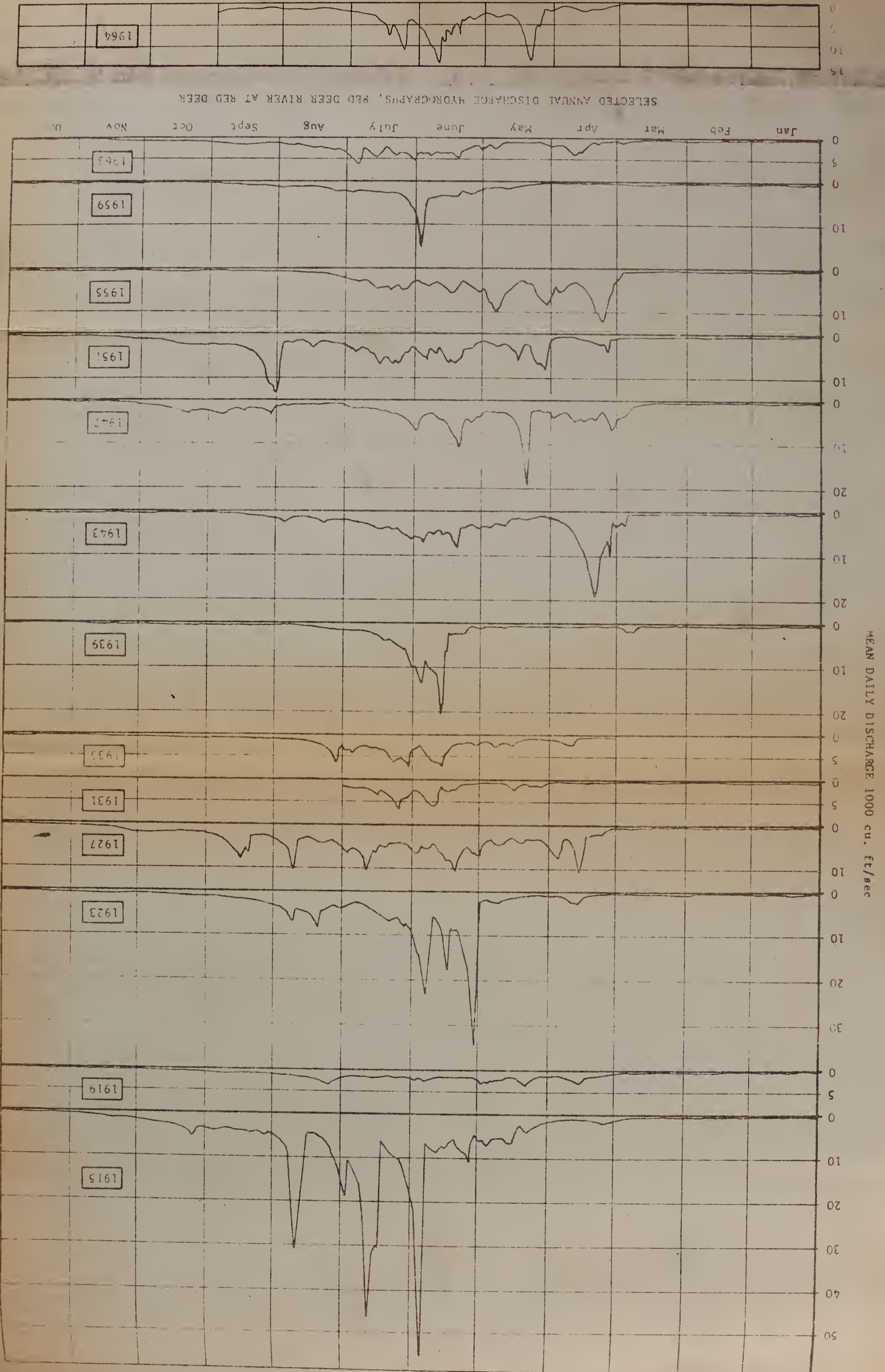


FIGURE 1.2



DISCHARGE HYDROGRAPH, RED DEER RIVER AT DUCHESS BRIDGE

SELECTED ANNUAL DISCHARGE HYDROGRAPHS, RED DEER RIVER AT RED DEER



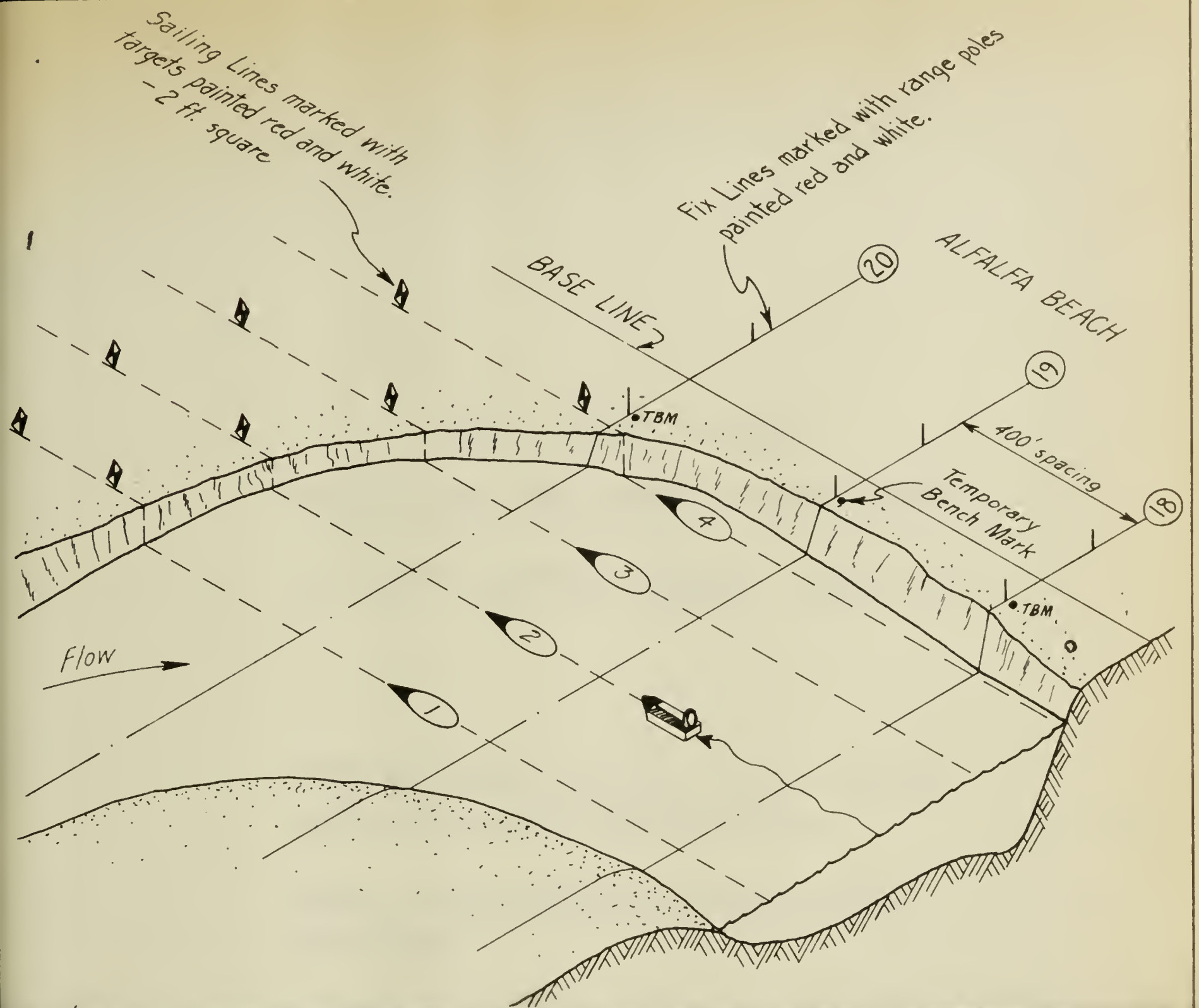


ILLUSTRATION OF HORIZONTAL CONTROL SURVEY, SAILING PROCEDURE AND PHOTOGRAPH OF AIR BOAT



FIGURE 3.1

RED DEER RIVER STAGE and DISCHARGE HYDROGRAPH at North Duchess Bridge 1963-64

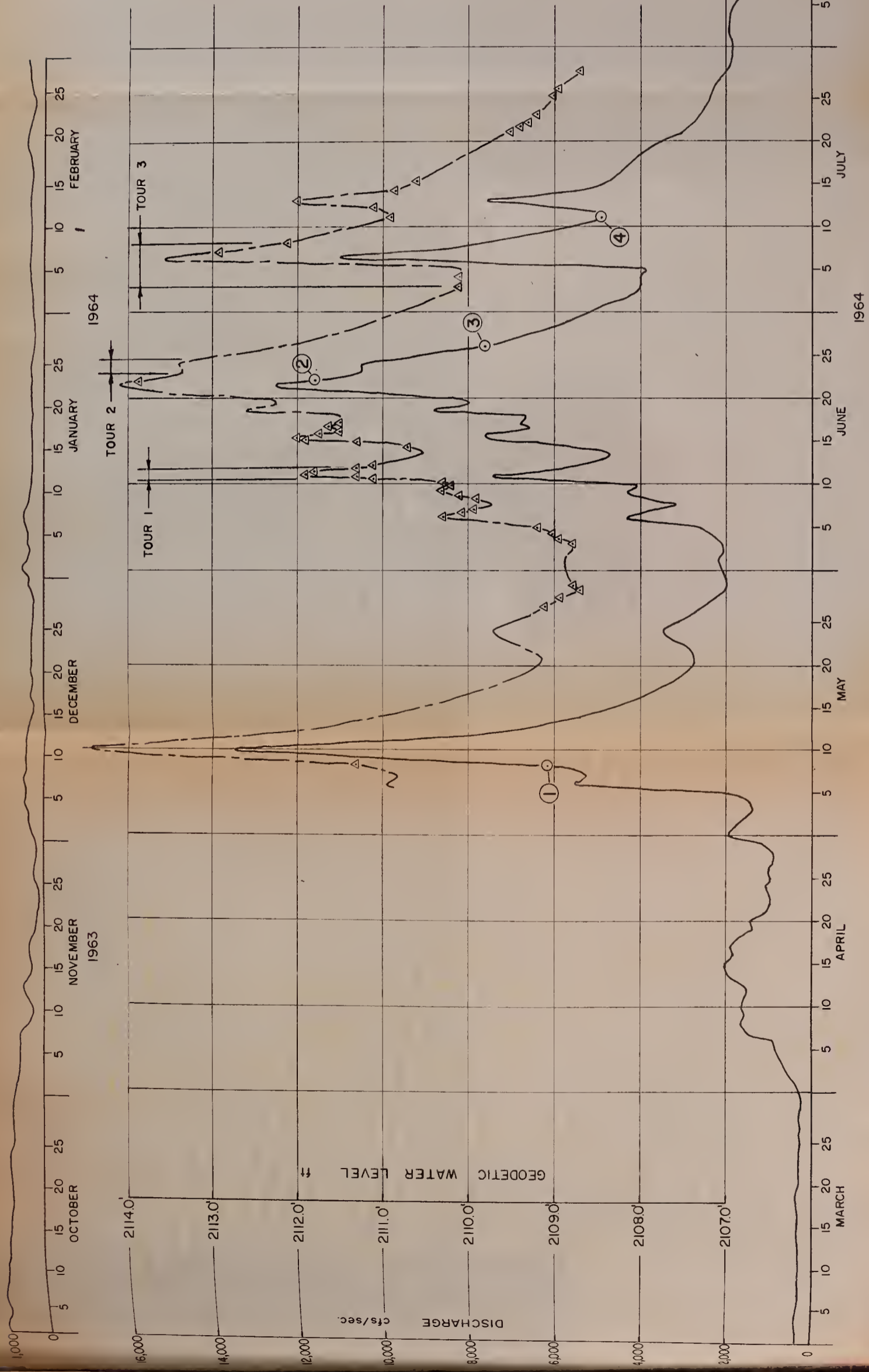
Stage by automatic recorder in terms of geodetic water level at North Duchess Bridge.

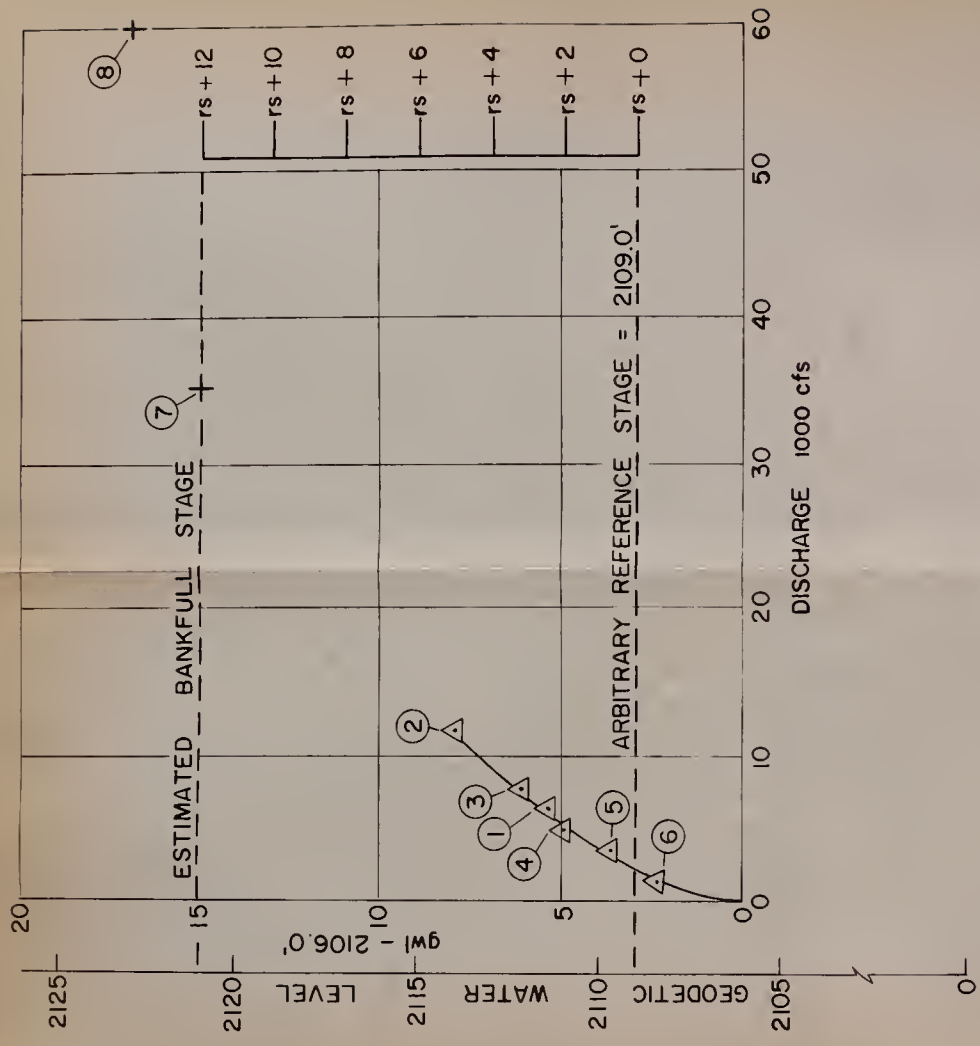
Check on water elevation by dumpy level or stick gauge.

Discharge

Discharge metered, see Table 3.1

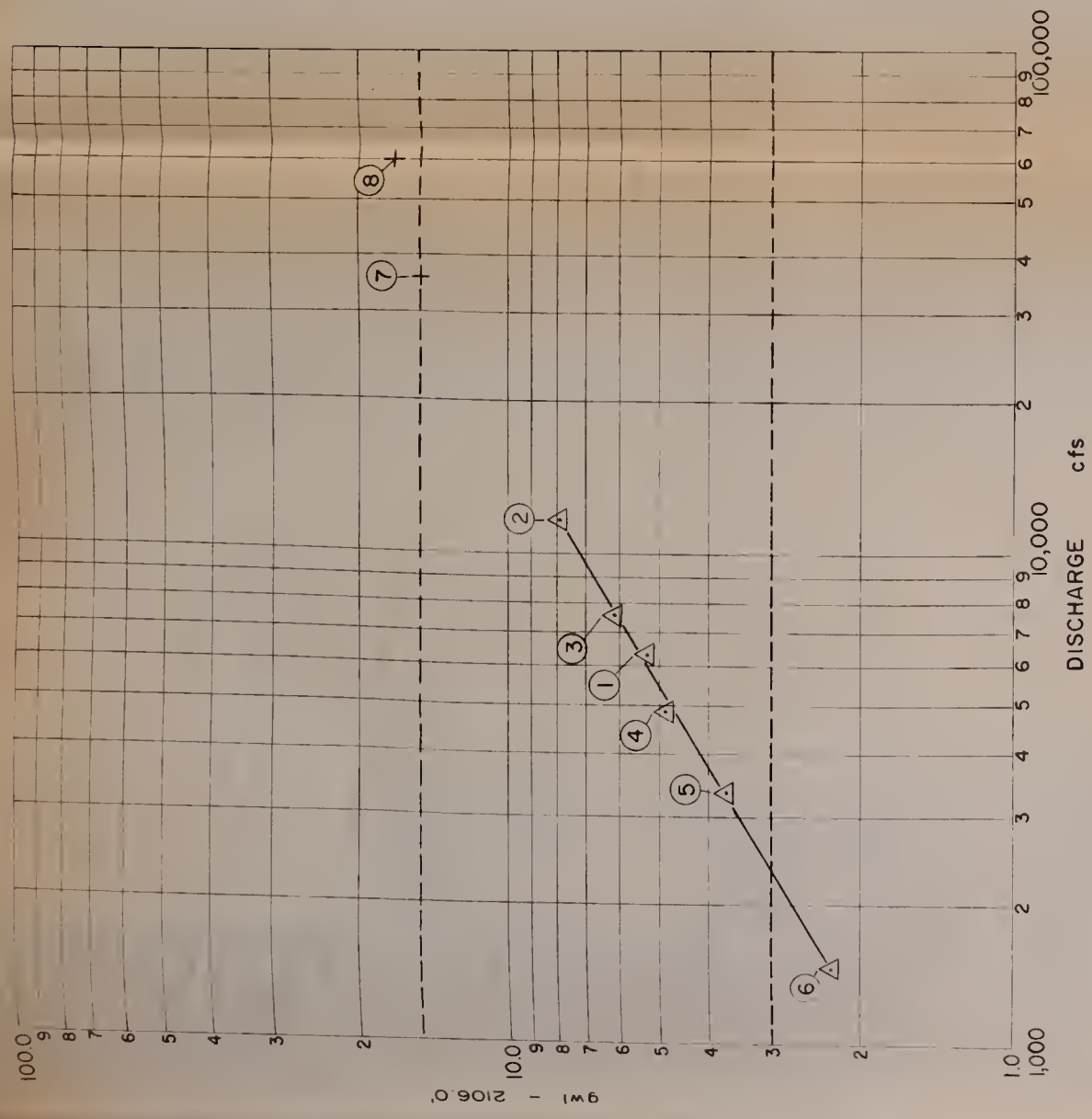
Figure 3.2



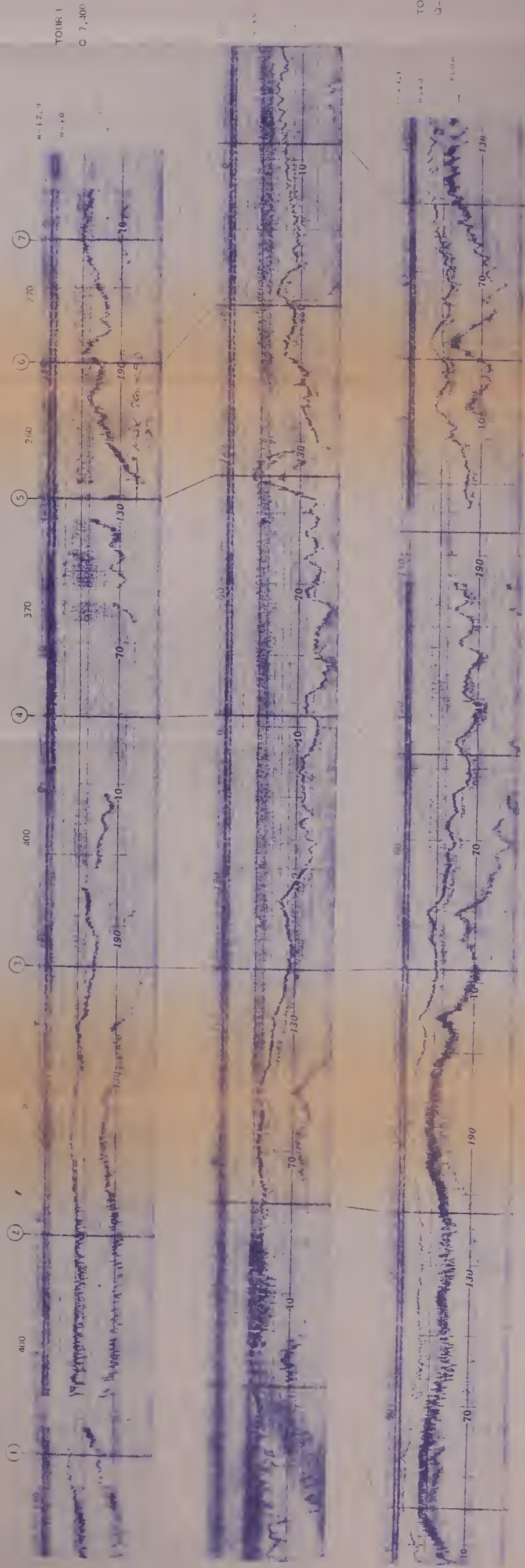


RED DEER RIVER
TENTATIVE
STAGE - DISCHARGE RELATION
AT
NORTH DUCHESS BRIDGE

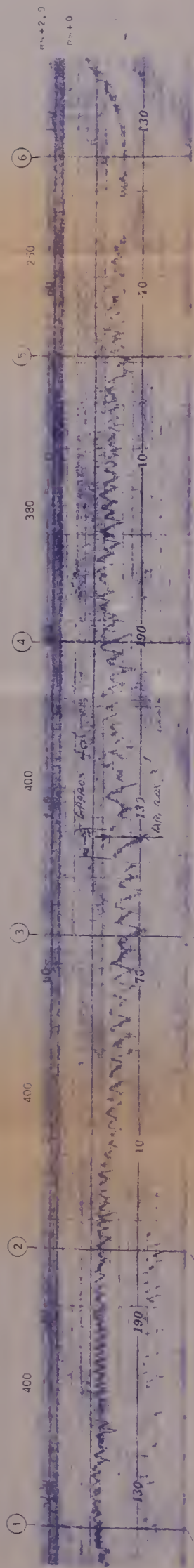
FIGURE 3.3



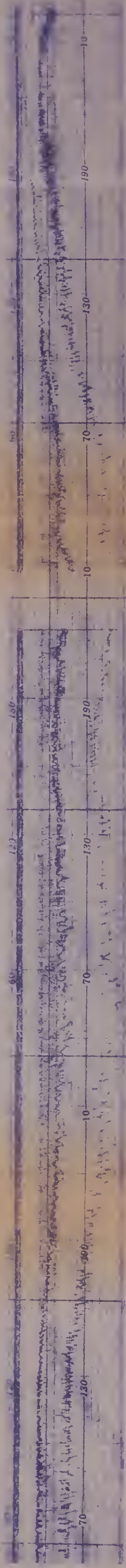
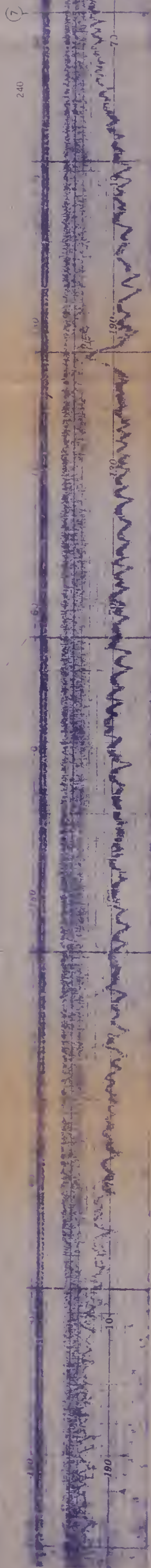
$$gw - 2106.0' = 0.0295 Q^{0.6}$$

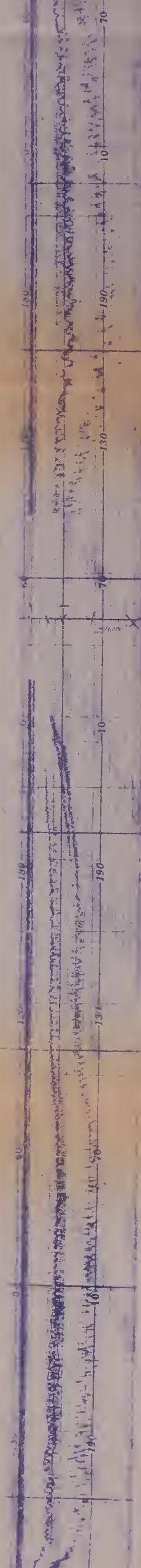
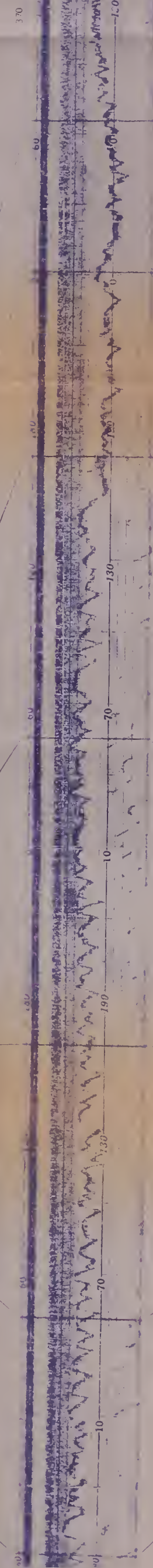
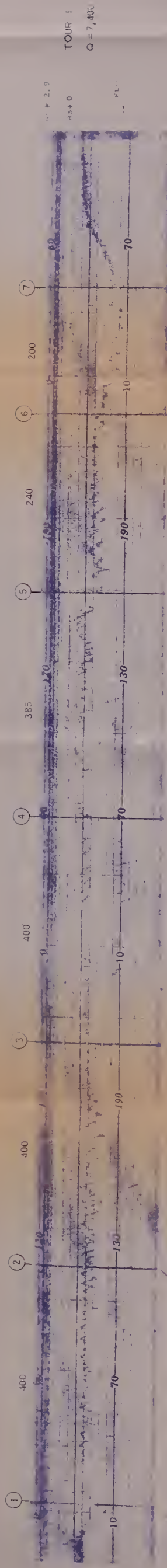


GOPHER BEACH
SAILING LINE NO. 1

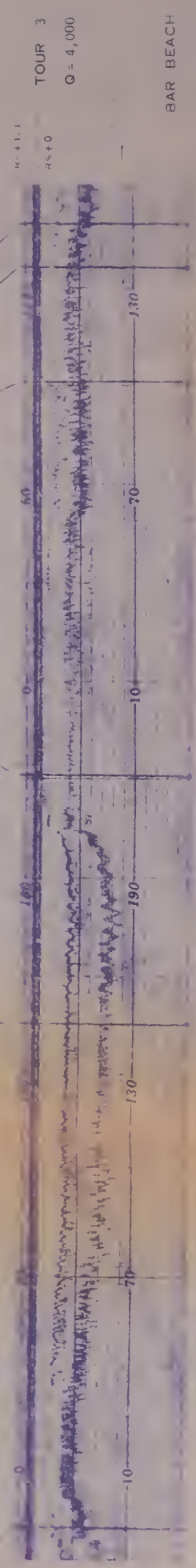
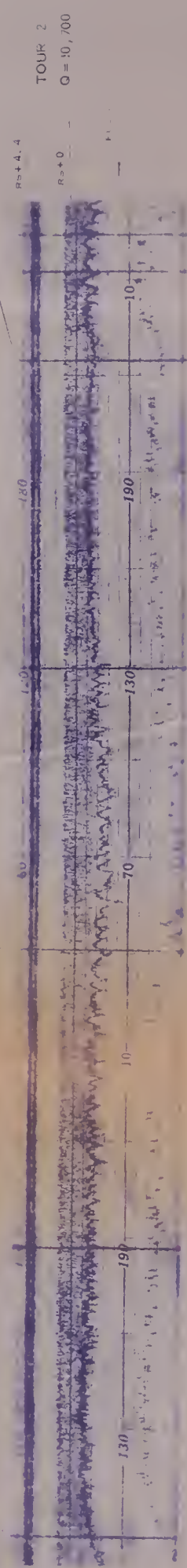
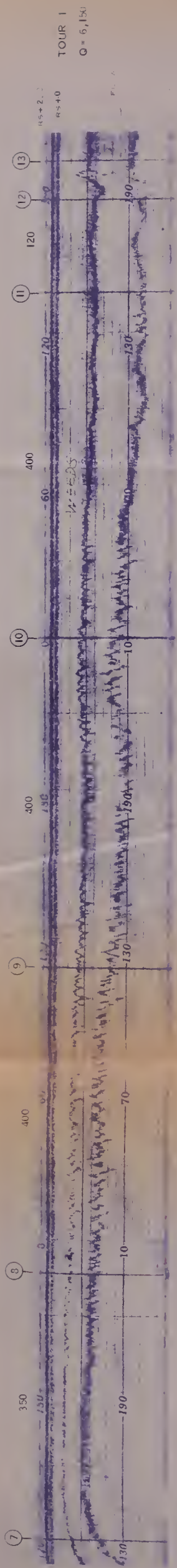


TOUR 1
Q = 7,400



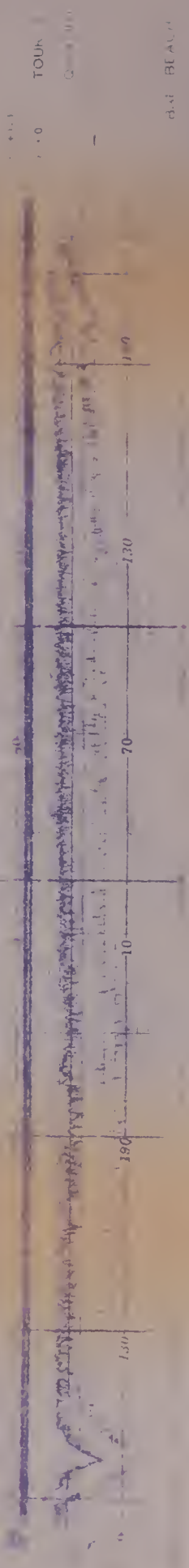
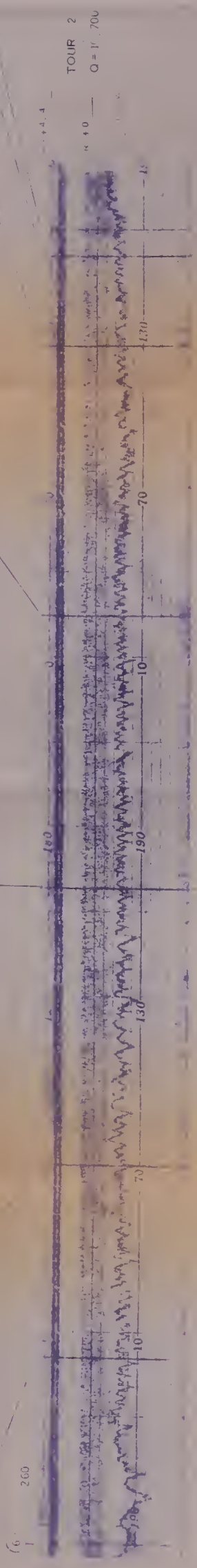
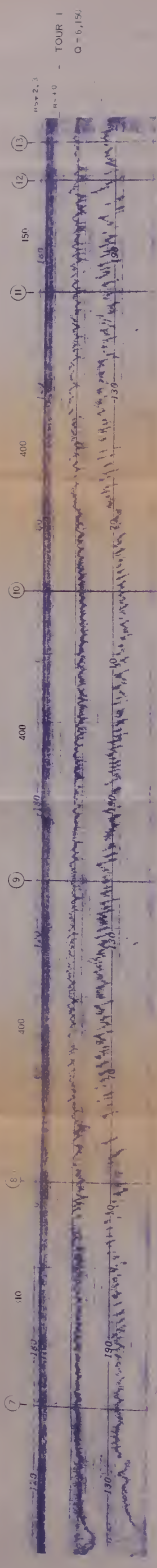


TOPOGRAPHIC REACH
SAILING LIFE NO.

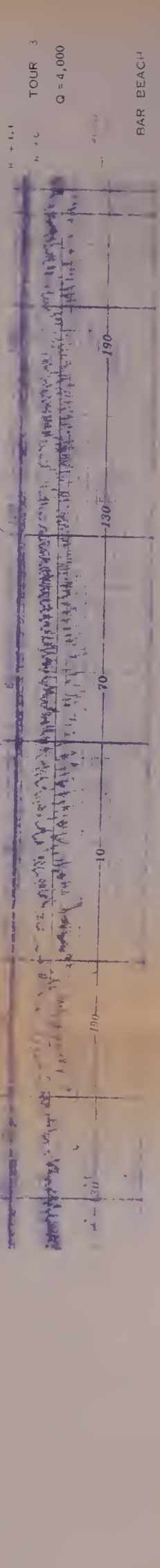
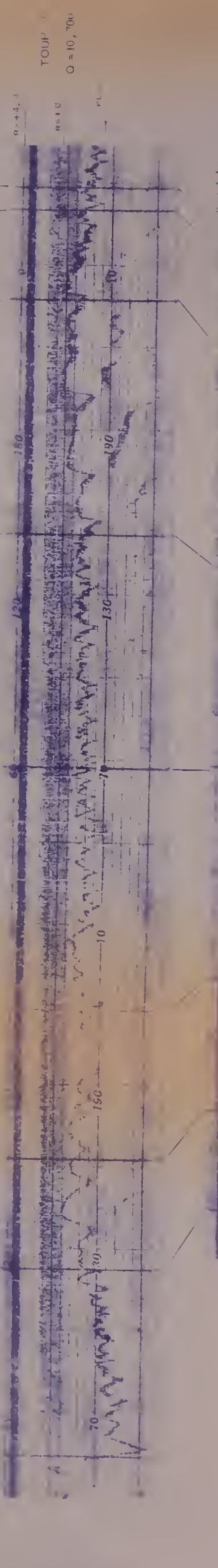
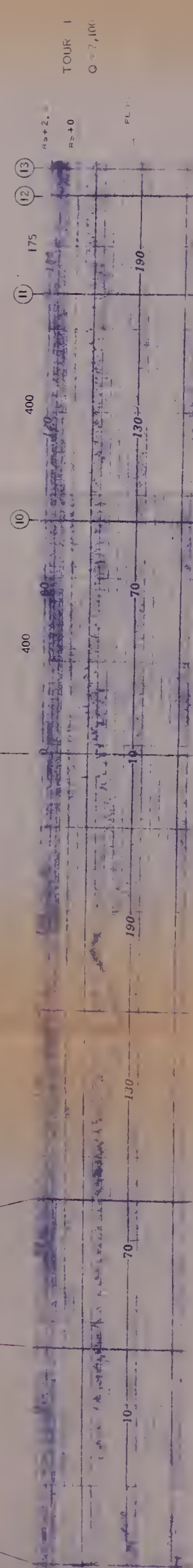
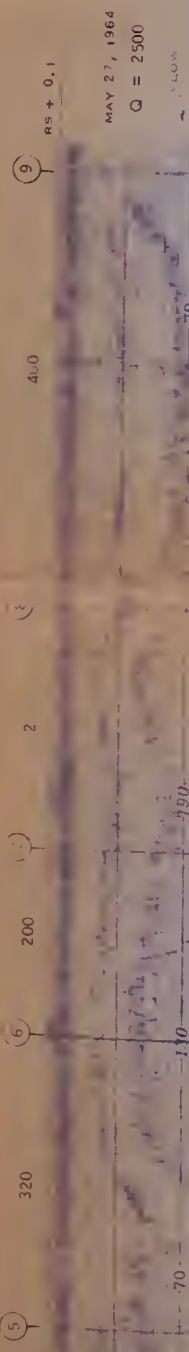


BAR BEACH
SAILING LINE NO. 1

FIGURE 3.7



3-4 BEACH
MULTI-C
F. (R)



BAR BEACH
SAILING LINE NO. 3

FIGURE 3

4.0

19

400

10

400

10

190

10

190

10

190

10

MAY 26, 1961
Q. 6.1

190

130

10

TOUR 1
Q. 6.1

190

130

10

190

130

10

190

130

10

190

130

TOUR
Q. 6.1

190

130

10

190

130

10

190

130

10

190

TOUR
Q. 6.1

190

130

10

190

130

10

190

130

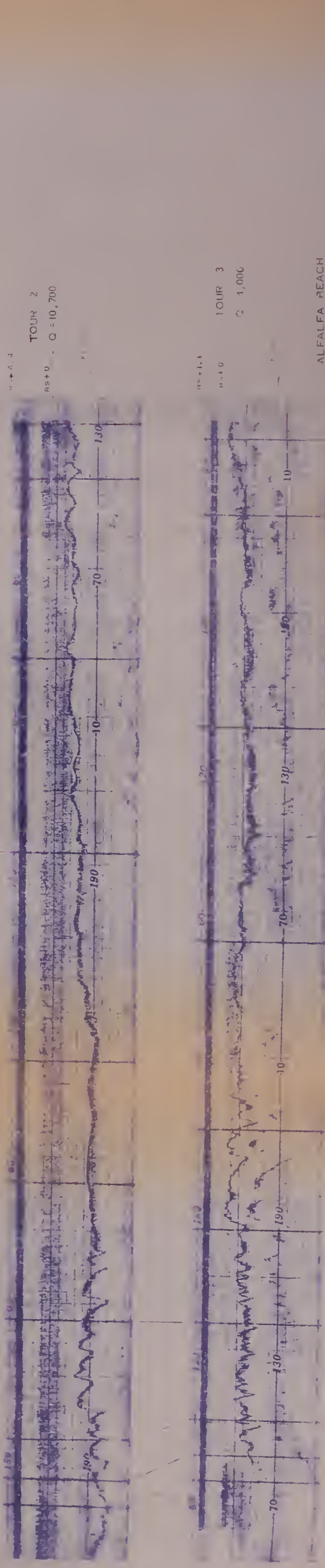
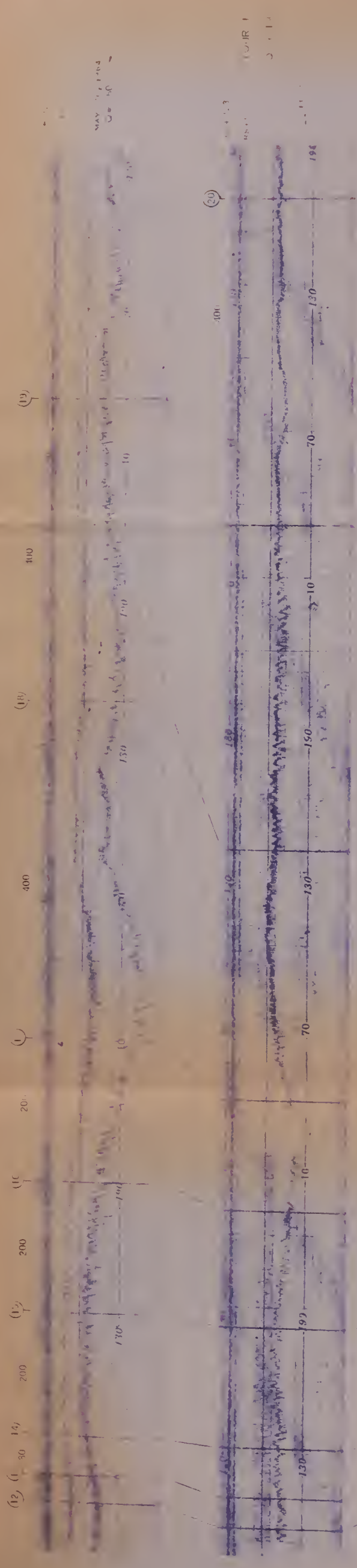
10

190

A FALFA EACH
SALIN LIP O

FIGURE

MAY 1963
Q = 10,000

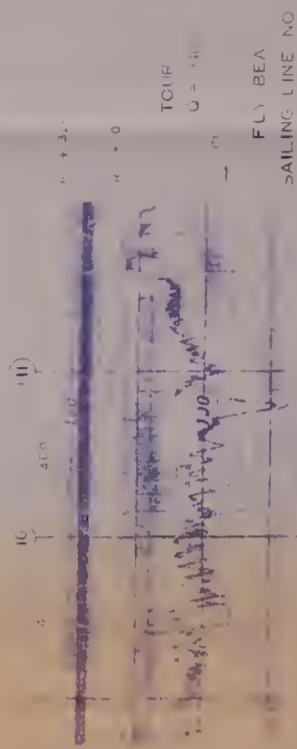


TOUR 2
Q = 10,700

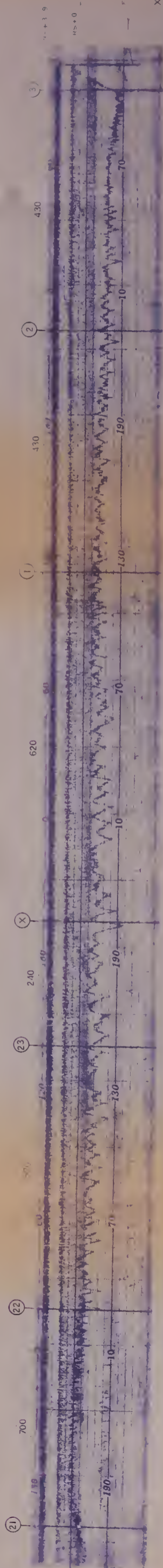
TOUR 3
Q = 4,000

ALFALFA REACH
SAILING LINE NO. 4

FIGURE 11



FLY BEA
SAILING LINE NO.



TOUR
Q = 9,600

FLY BEA
SAILING LINE NO.

FIGURE 2.12

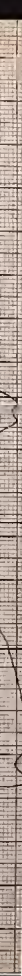
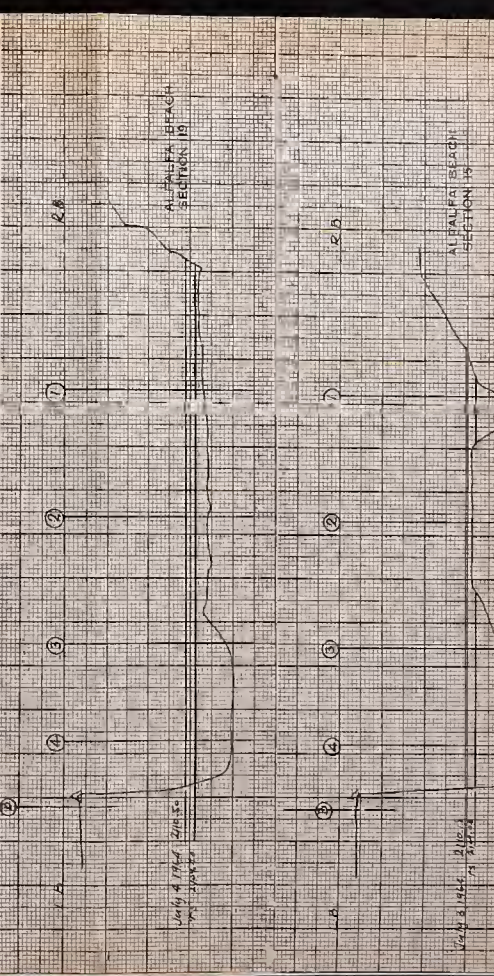
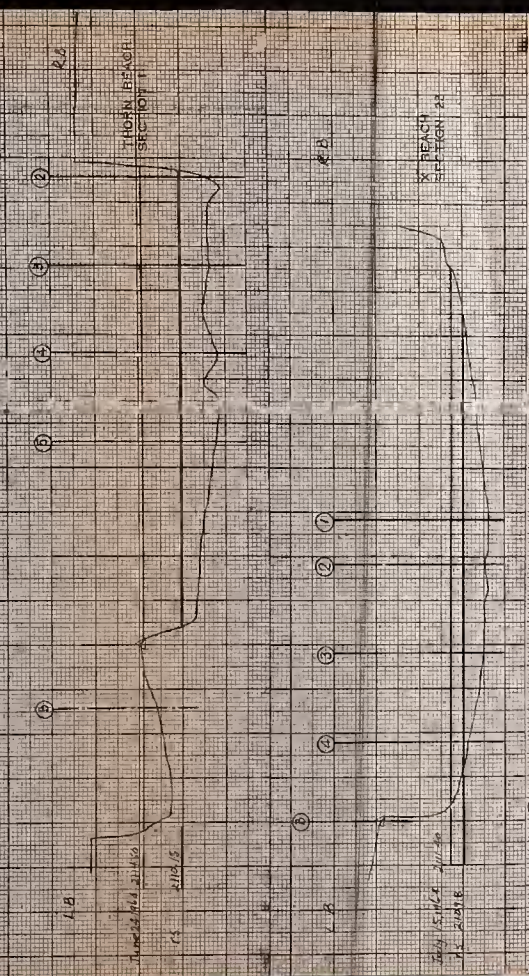
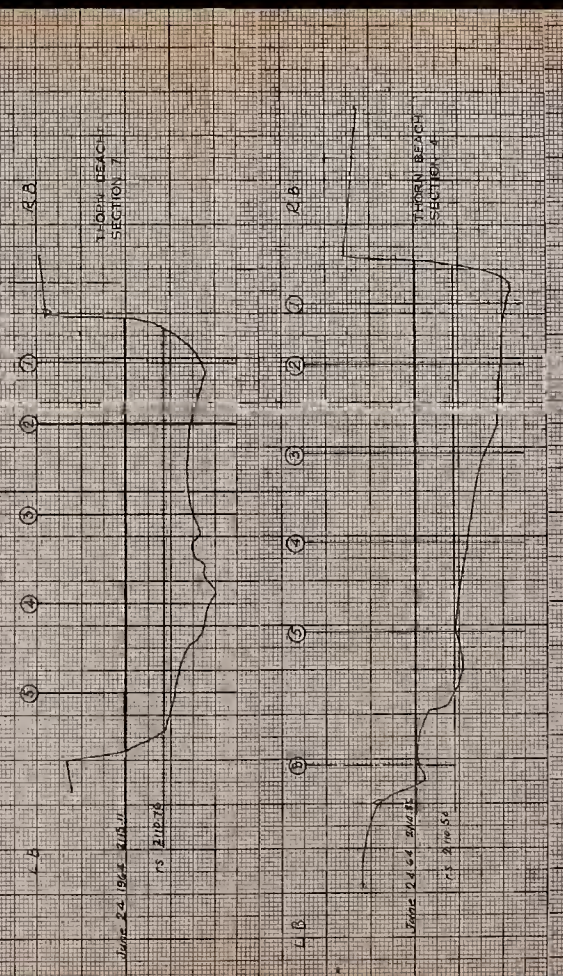
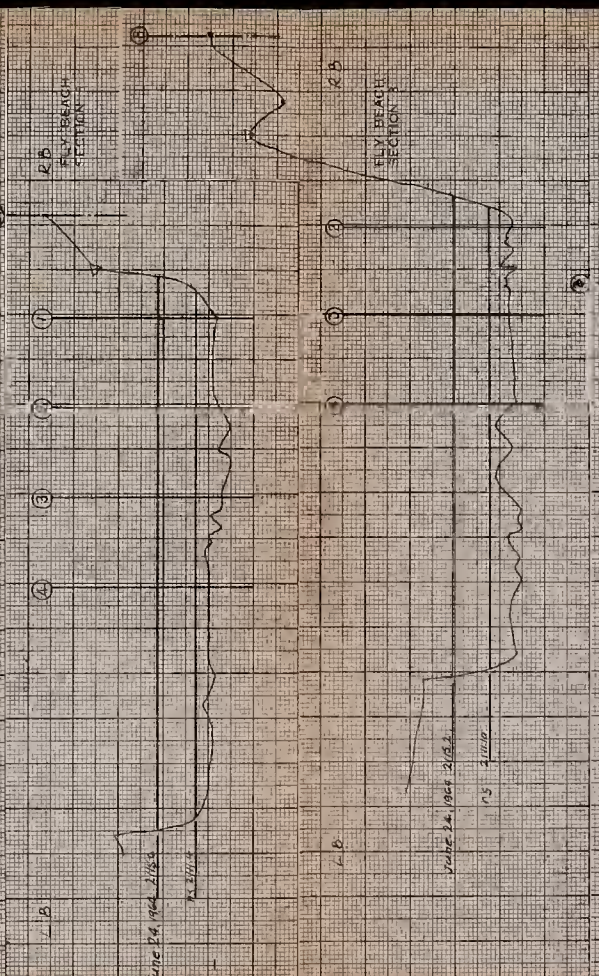
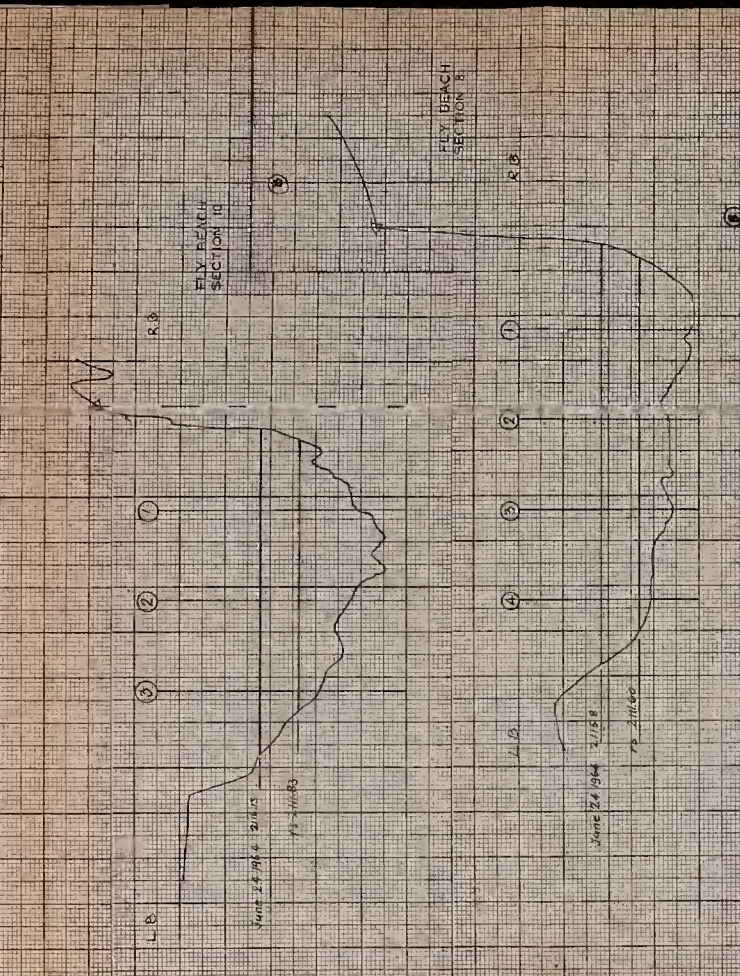
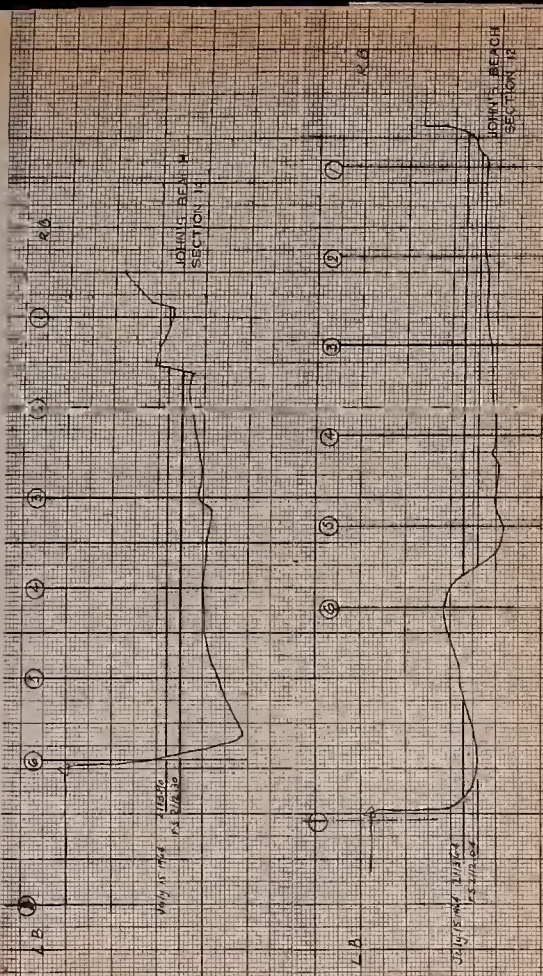
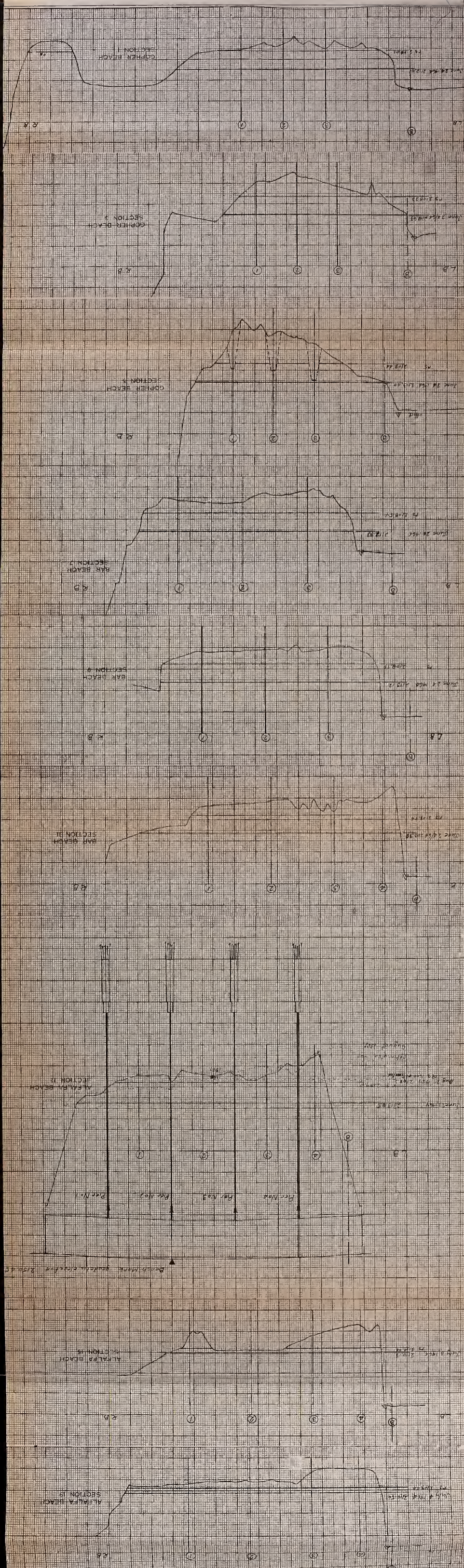


FIGURE 3.13

CHANNEL CROSS-SECTIONS OF STUDY LENGTH
 DRAWN LOOKING DOWNSTREAM
 SCALES: Vertical, 1 in = 10 ft. Horizontal, 1 in = 100 ft.



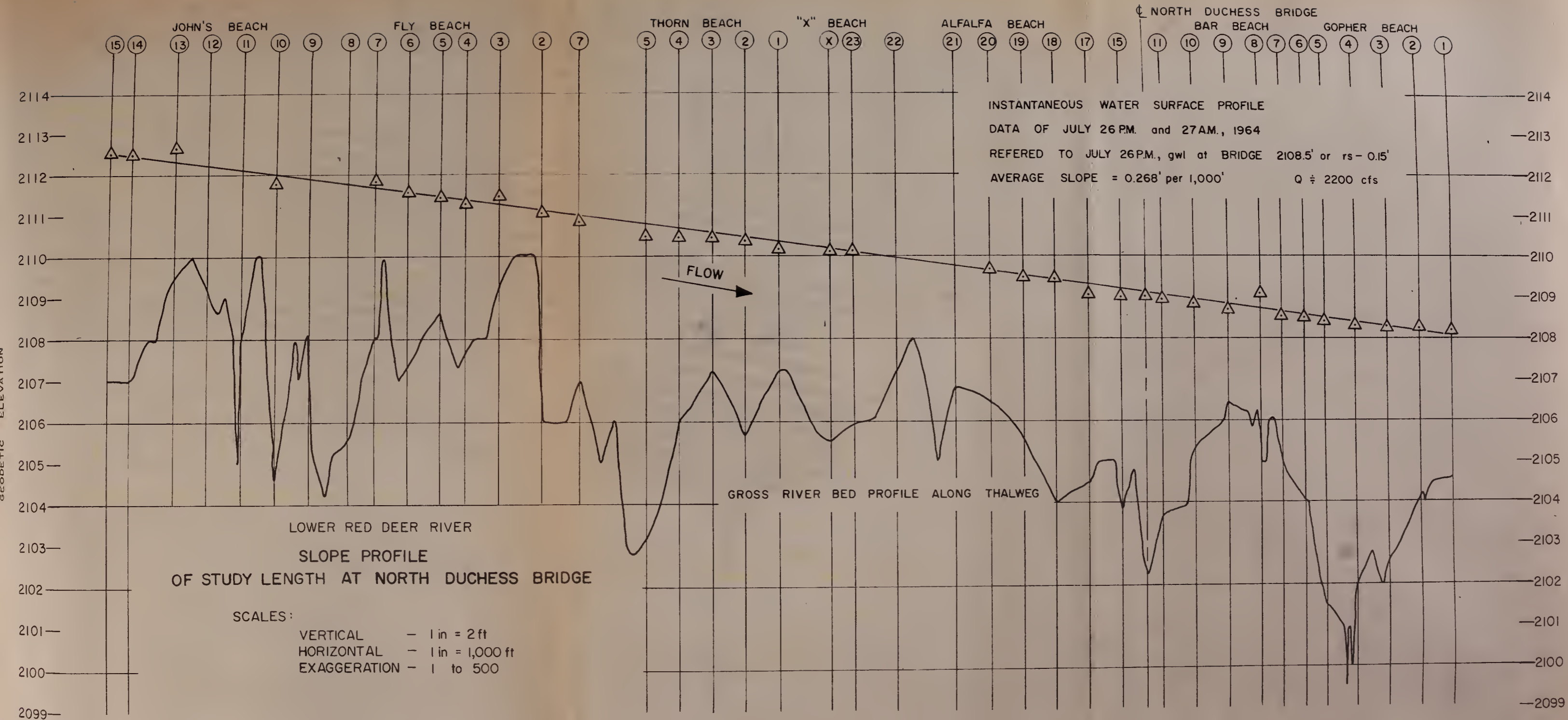
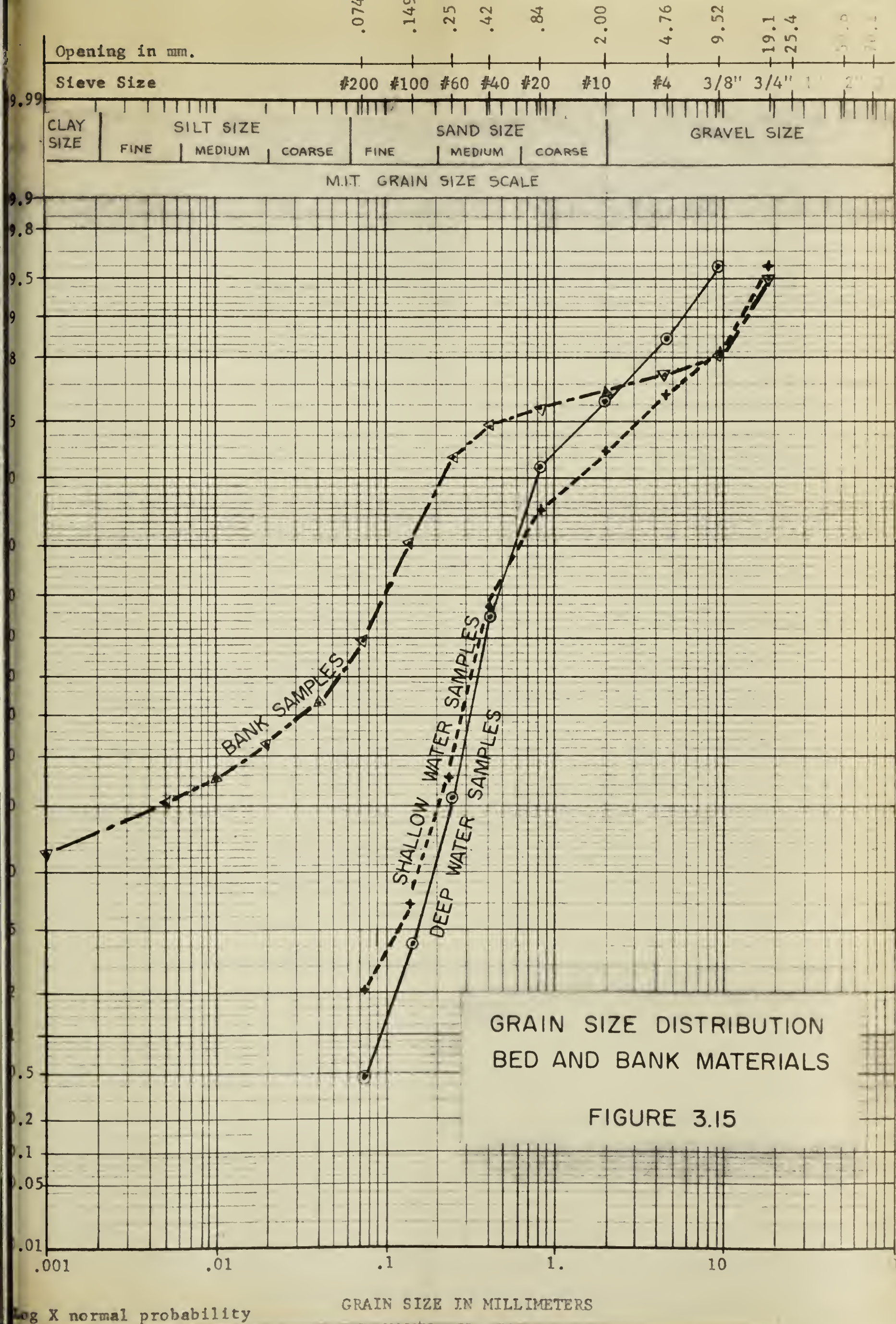
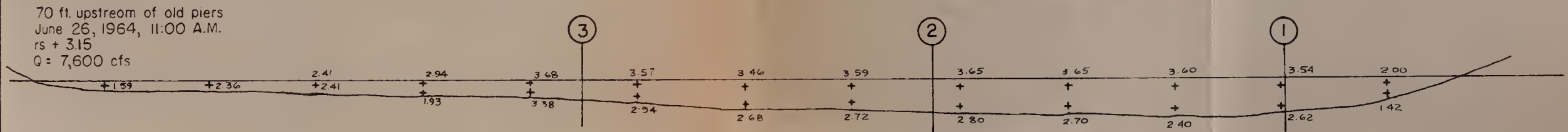
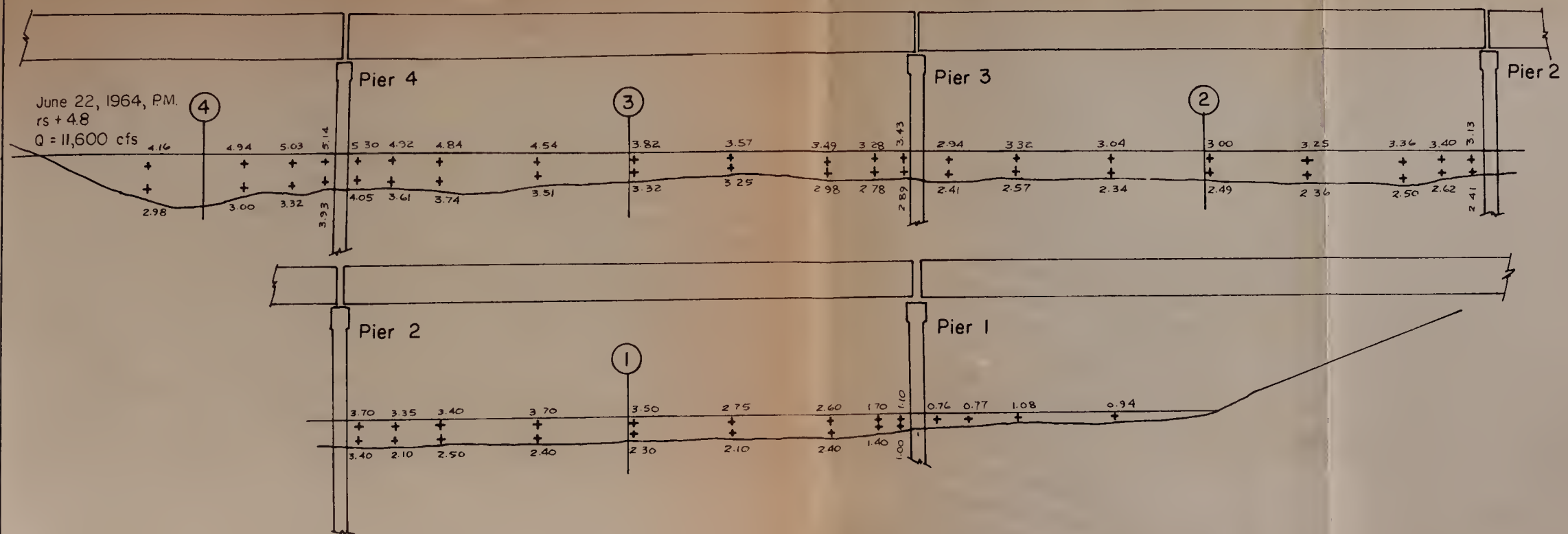
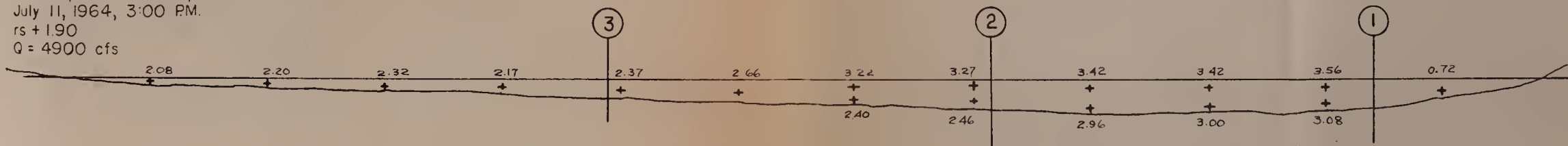


Figure 3.14





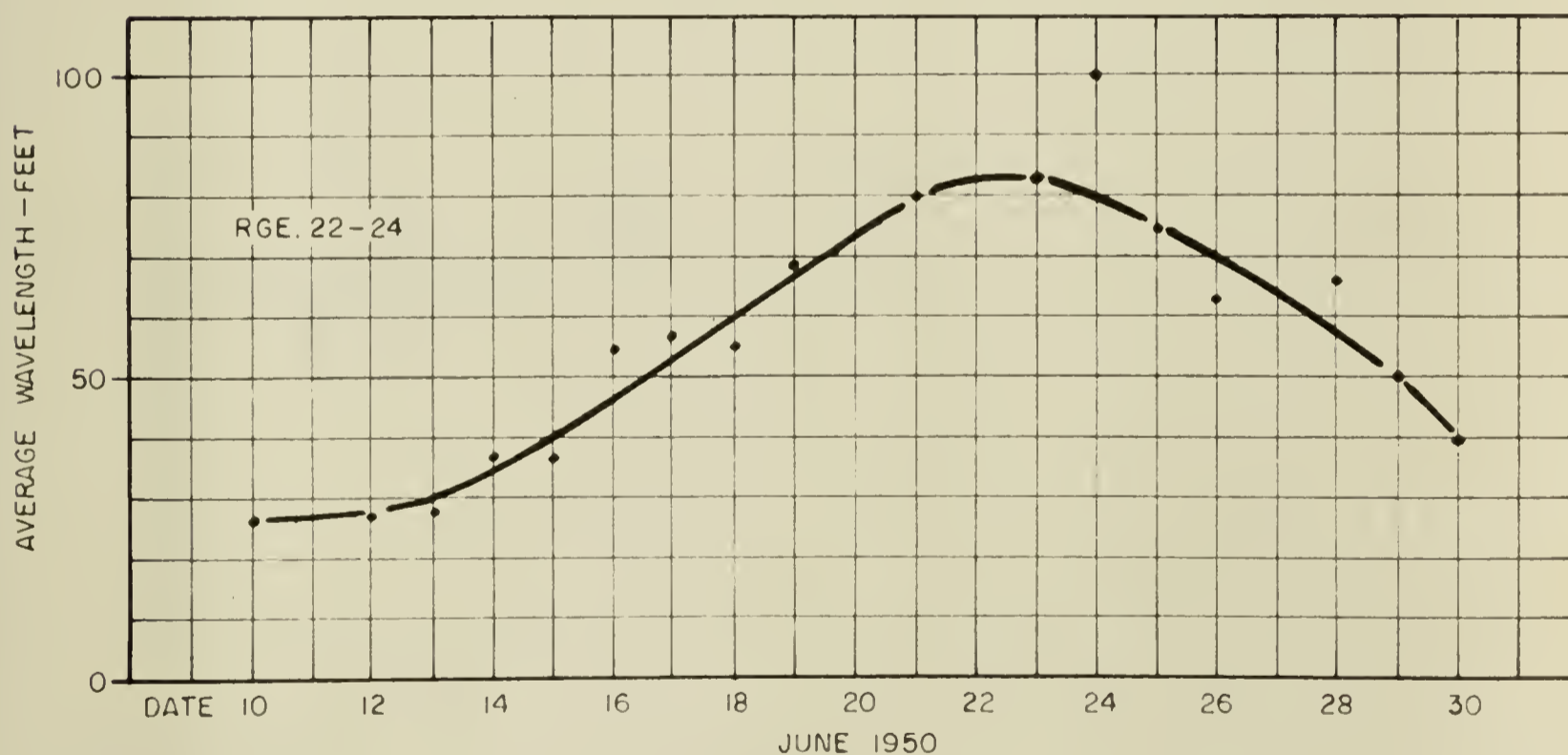
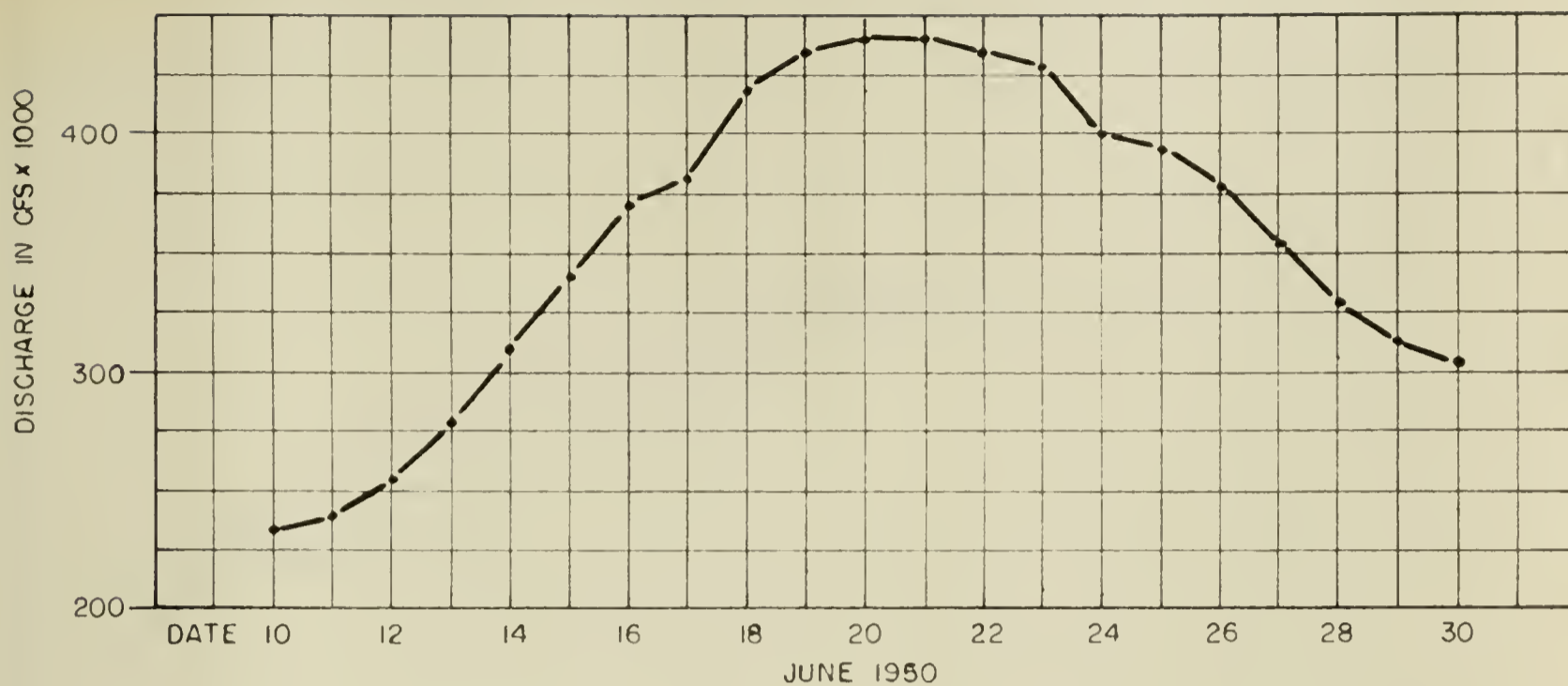
70 ft. upstream of old piers
July 11, 1964, 3:00 P.M.
rs + 1.90
Q = 4900 cfs



Scale: 1 in. = 30 ft.
Velocity Given in Feet per Second

STUDY LENGTH
LOWER RED DEER RIVER
VELOCITY DISTRIBUTIONS

FIGURE 3.16



FRASER RIVER DUNE DIMENSIONS

PLOTTED FROM PRETIOUS AND BLENCH (1950)

The reach under observation was at the mouth of the river and the discharge was subject to tidal swing.

FIGURE 4.1

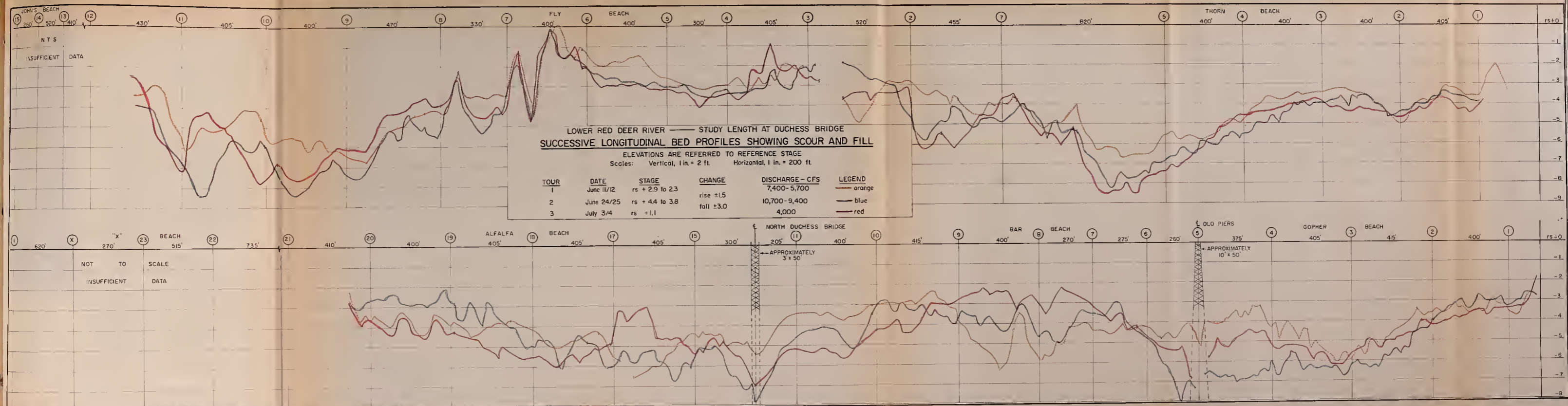
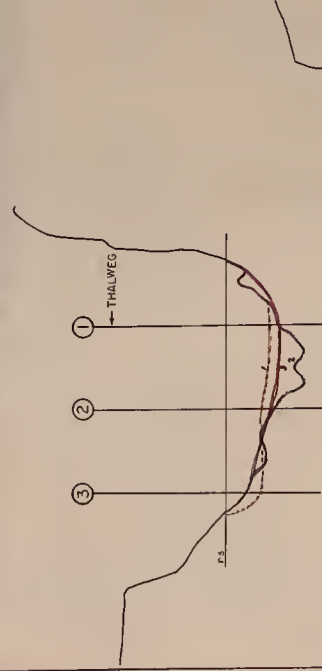
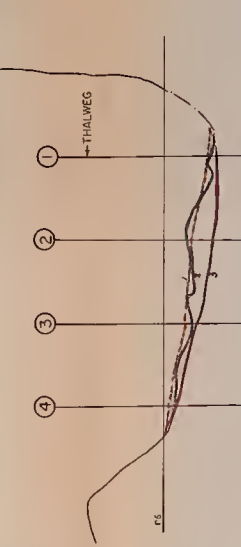


FIGURE 4.2

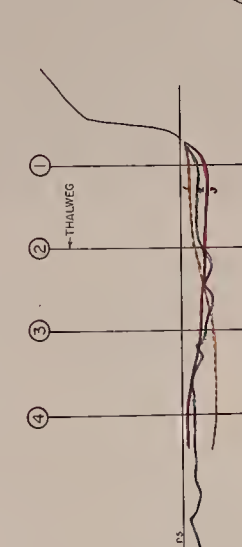
FLY BEACH
SECTION 10



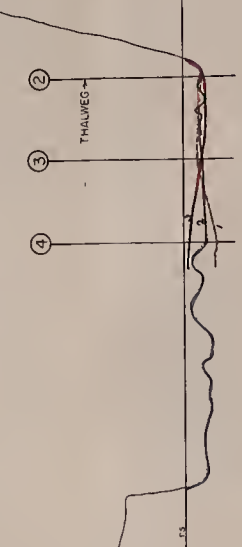
FLY BEACH
SECTION 8



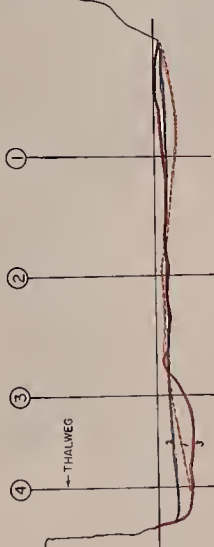
FLY BEACH
SECTION 6



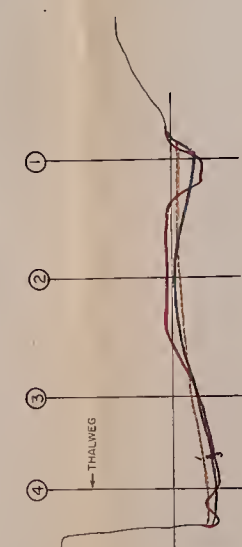
FLY BEACH
SECTION 3



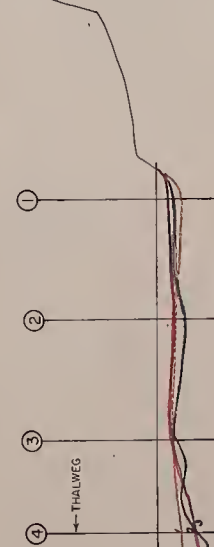
ALFALFA BEACH
SECTION 19



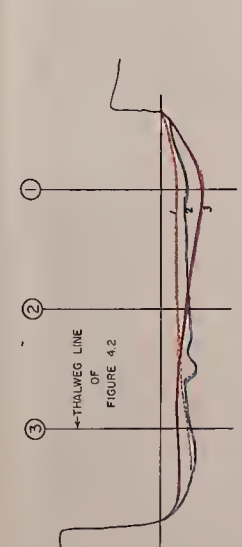
ALFALFA BEACH
SECTION 15



BAR BEACH
SECTION 11



BAR BEACH
SECTION 9



SUCCESSIVE TRANSVERSE BEO PROFILES

DRAWN LOOKING DOWNSTREAM

SCALES: Vertical, 1 in. = 10 ft. Horizontal, 1 in. = 100 ft.

Tour 1 ———
Tour 2 ———
Tour 3 ———

STUDY LENGTH
LOWER RED DEER RIVER

SUCCESSIVE BED CONTOURS
AT SHARP BEND

Tour I
Stage rs + 2.1
Q = 5700 cfs

Scale: 1 in. = 200 ft.
Depths are referred to reference stage

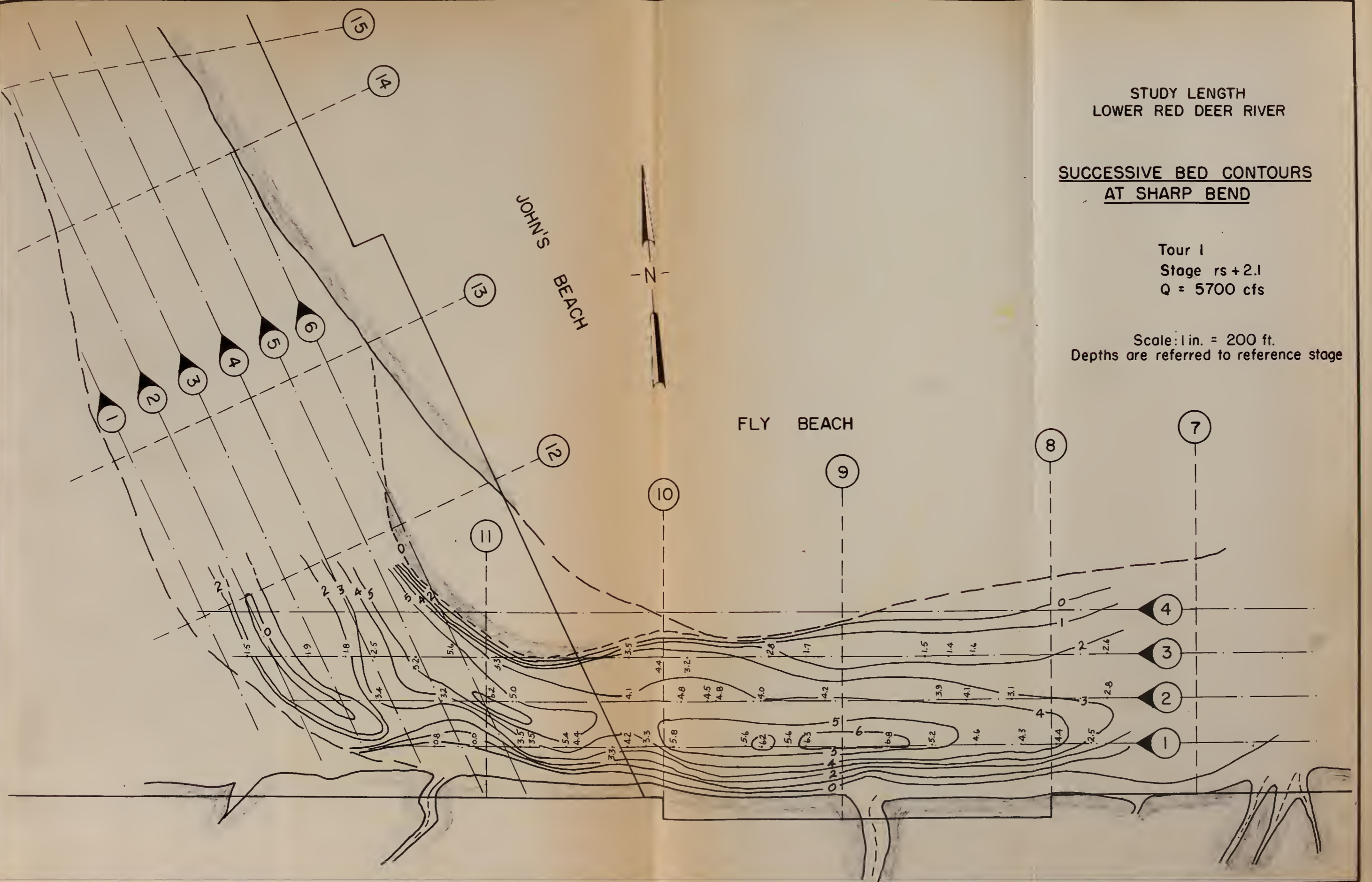


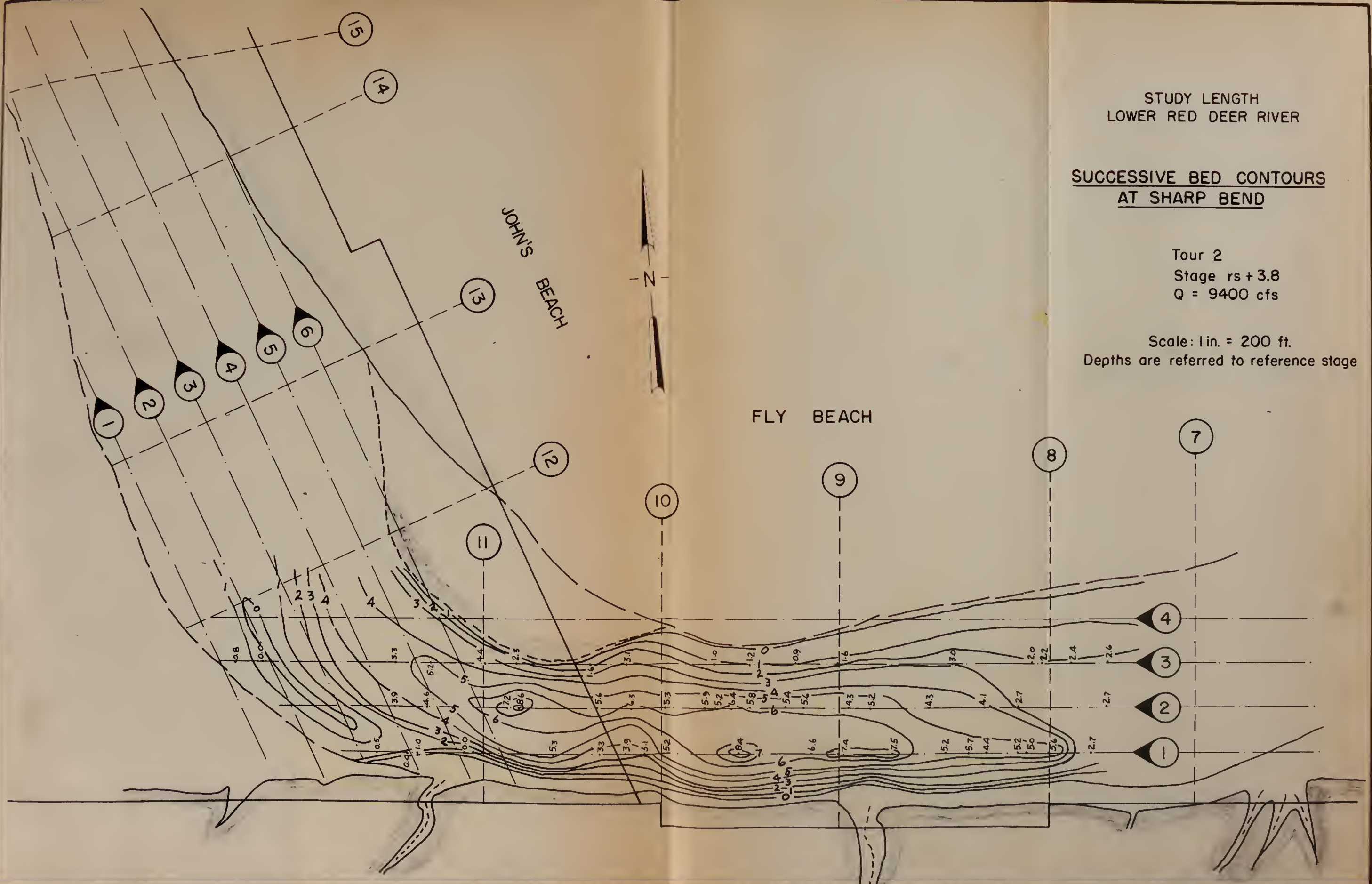
FIGURE 4.4 (a)

STUDY LENGTH
LOWER RED DEER RIVER

SUCCESSIVE BED CONTOURS
AT SHARP BEND

Tour 2
Stage $rs + 3.8$
 $Q = 9400$ cfs

Scale: 1 in. = 200 ft.
Depths are referred to reference stage



STUDY LENGTH
LOWER RED DEER RIVER

SUCCESSIVE BED CONTOURS
AT SHARP BEND

Tour 3
Stage rs +1.1
Q = 4000 cfs

Scale: 1 in. = 200 ft.
Depths are referred to reference stage

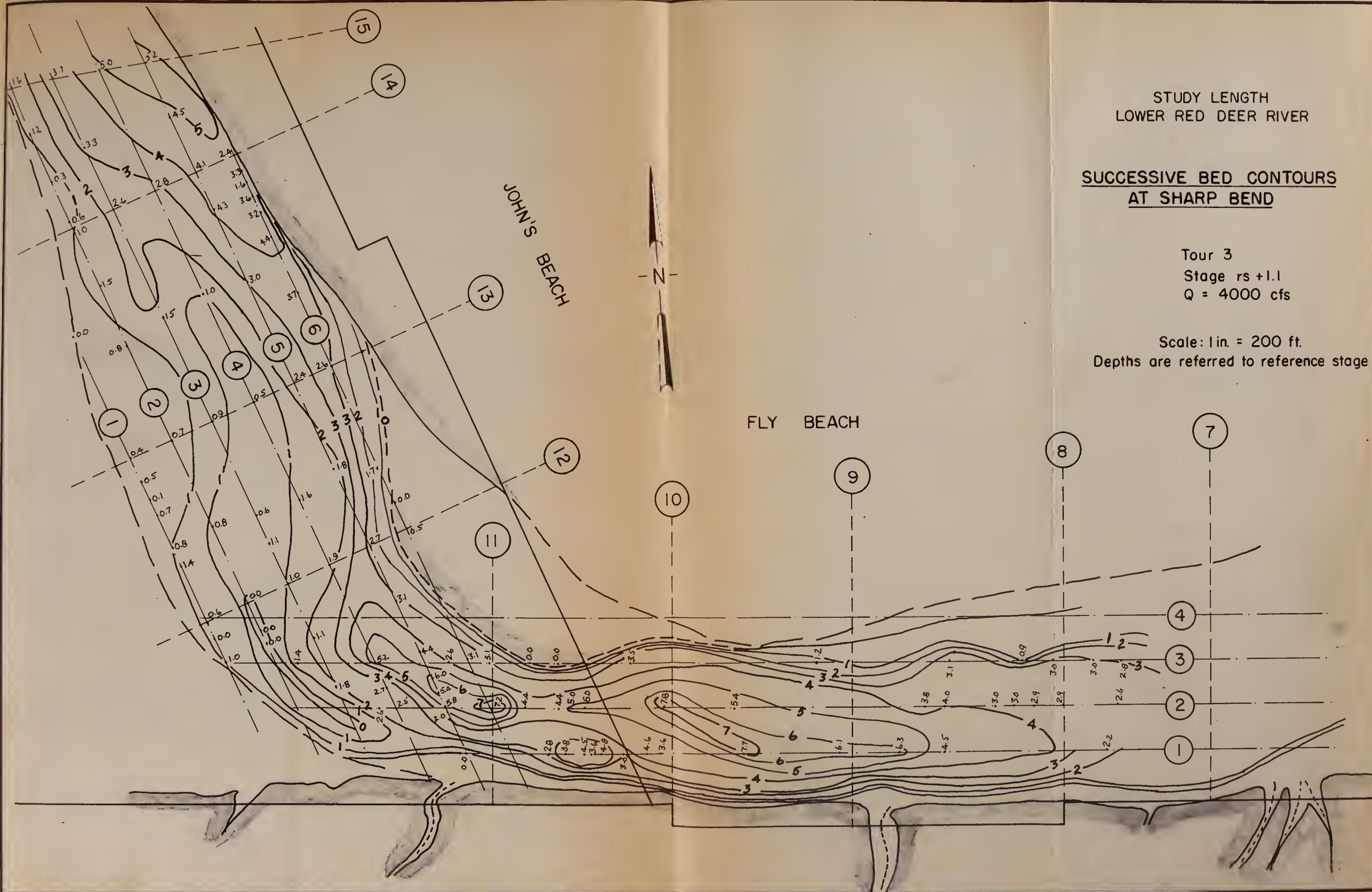


FIGURE 4.4 (c)

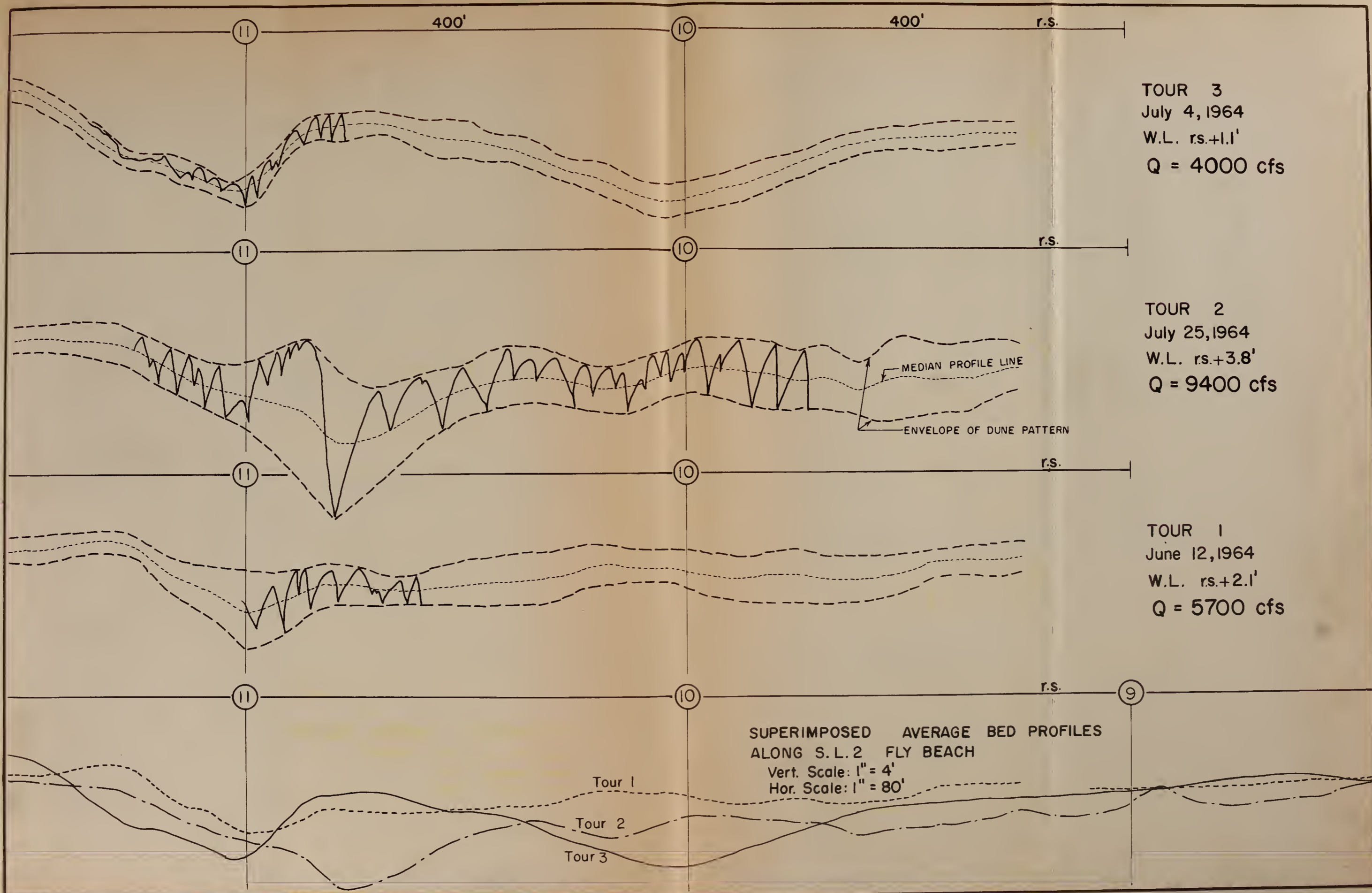
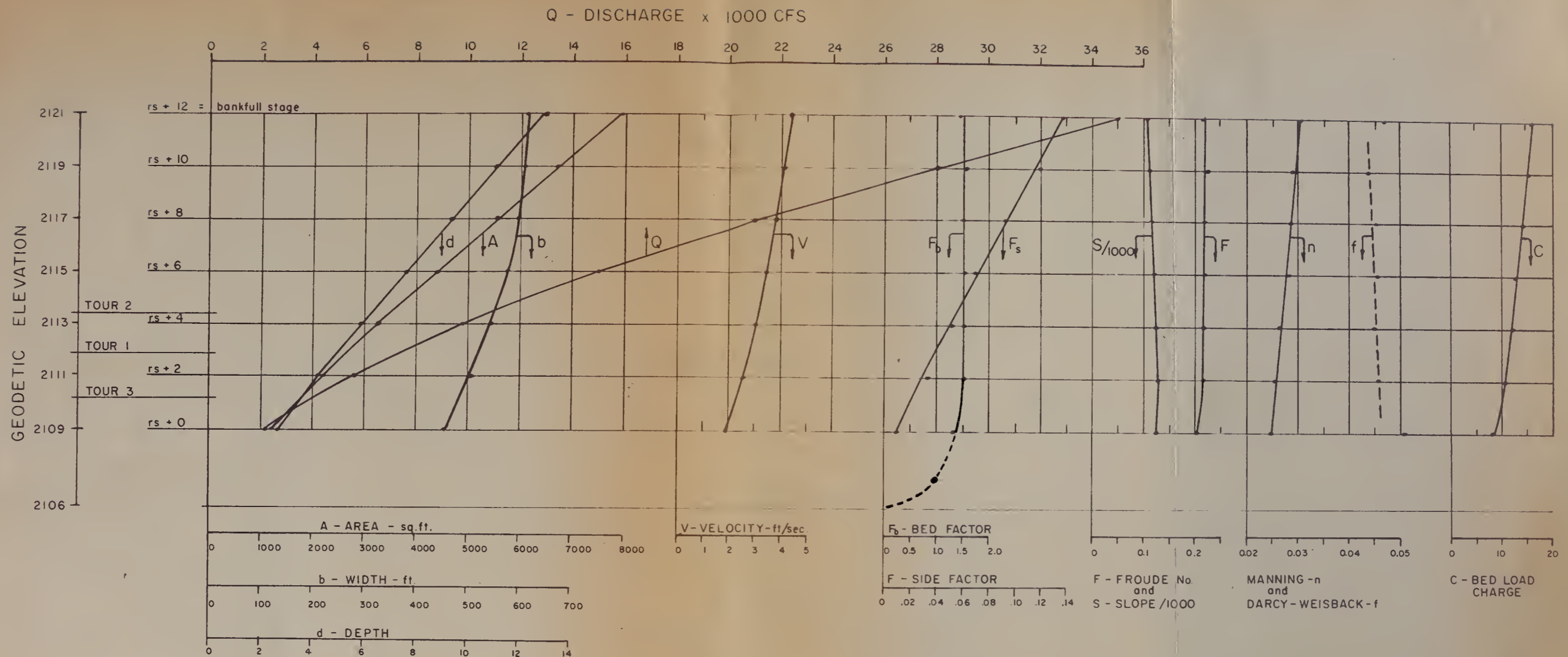
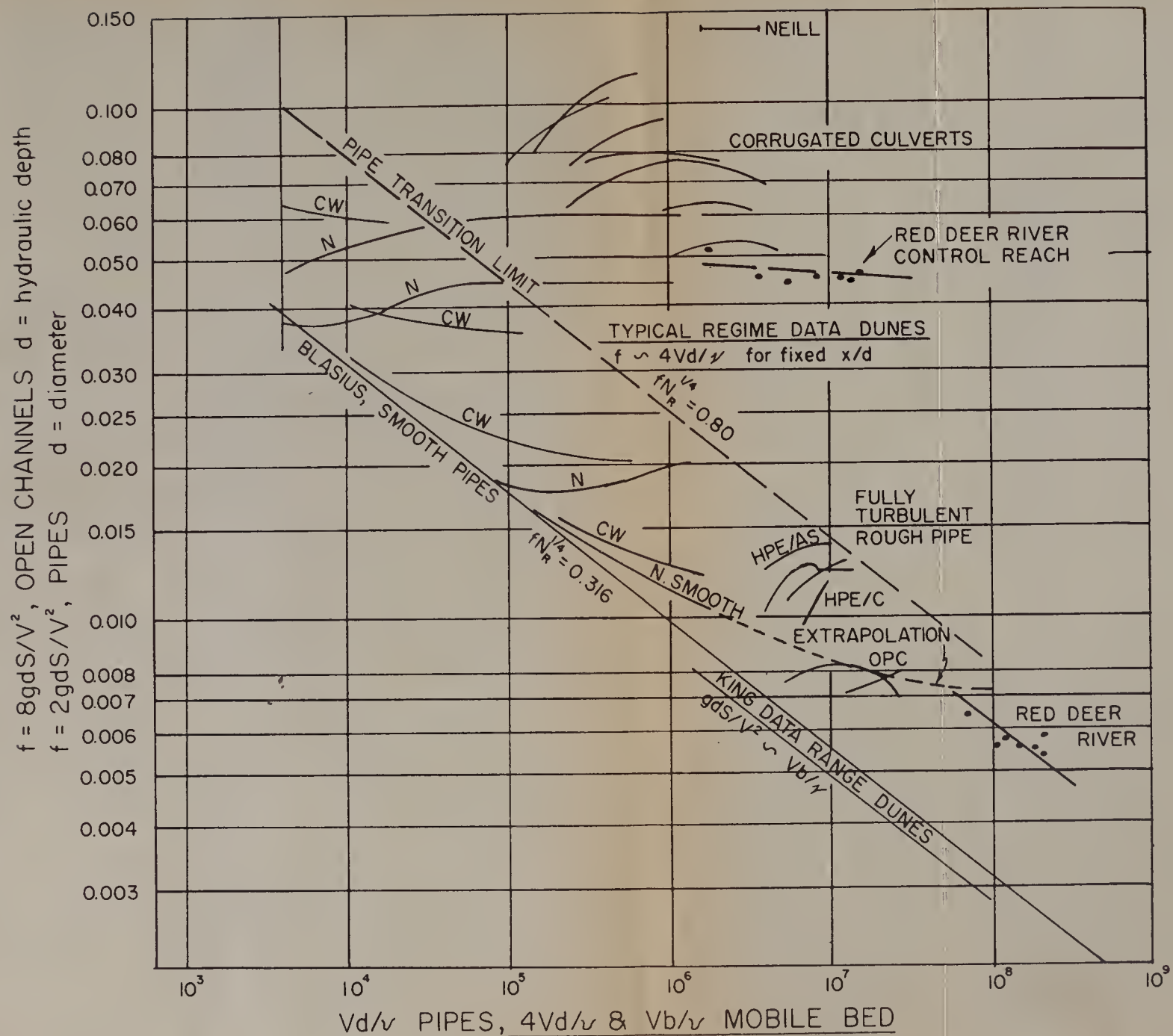


FIGURE 4.5

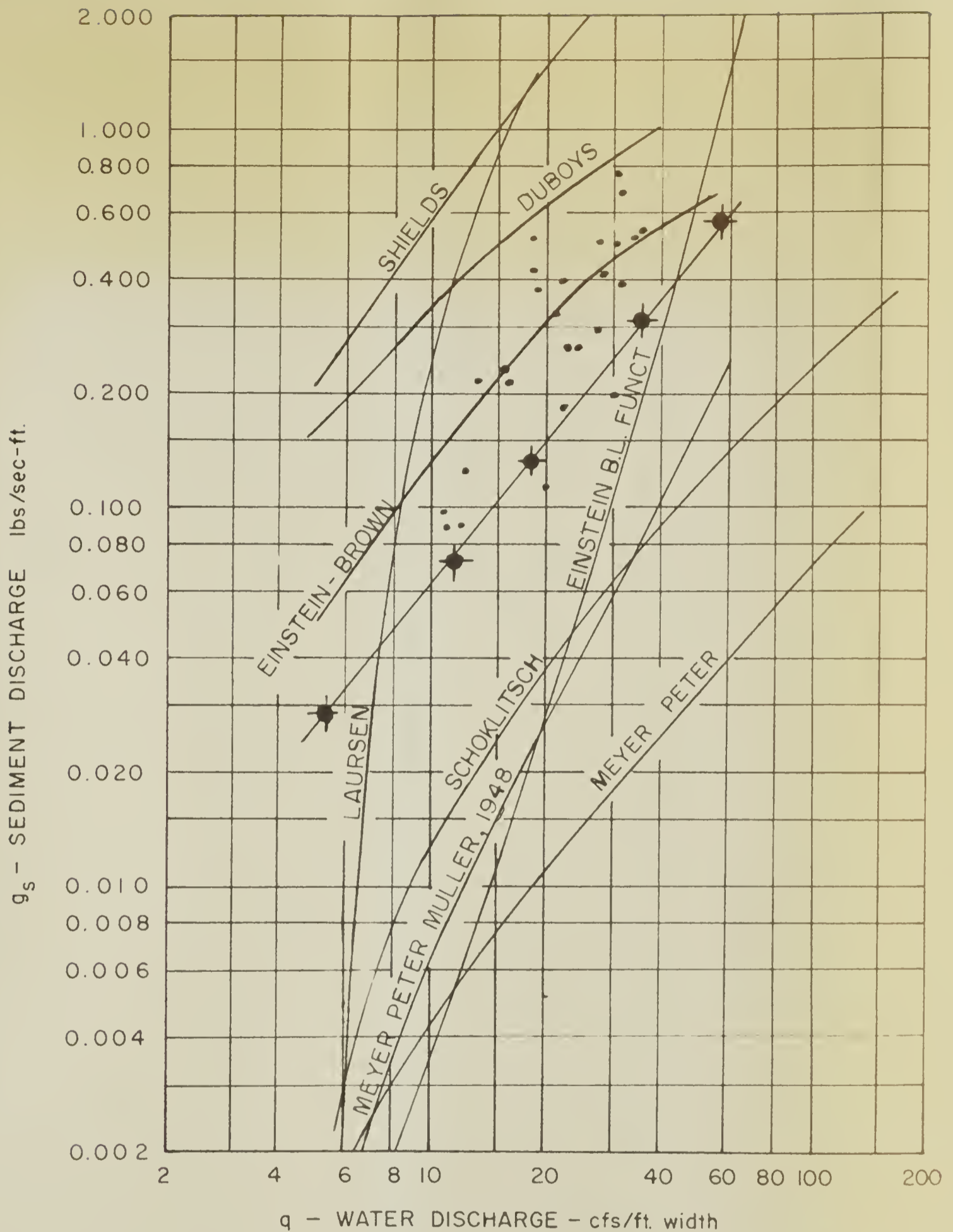


PLOT OF AVERAGE CROSS-SECTIONAL DATA FOR STUDY LENGTH
LOWER RED DEER RIVER AT DUCHESS BRIDGE



FRICTION FACTOR DIAGRAM
 DATA RANGES COMPARED

Figure 5.2



Computed sediment rating curves (extracted from reference 19 for the Colorado River at Taylor's Ferry according to several formulas. The measured surface slopes varied from .000147 to .000333. In the calculations the arithmetic average of all measured slopes or .000217 was used. The water temperature varied between 48 and 81° F.

For comparison purposes, data for the Red Deer River Control Reach is as follows:

$$S = .000268$$

$$D_{mm} = .34 \text{ mm}$$

$$T = 60^\circ \text{ F.}$$

★ Computed according to Regime Theory $f'''(C)$ function, Chapter V.

Figure 5.3

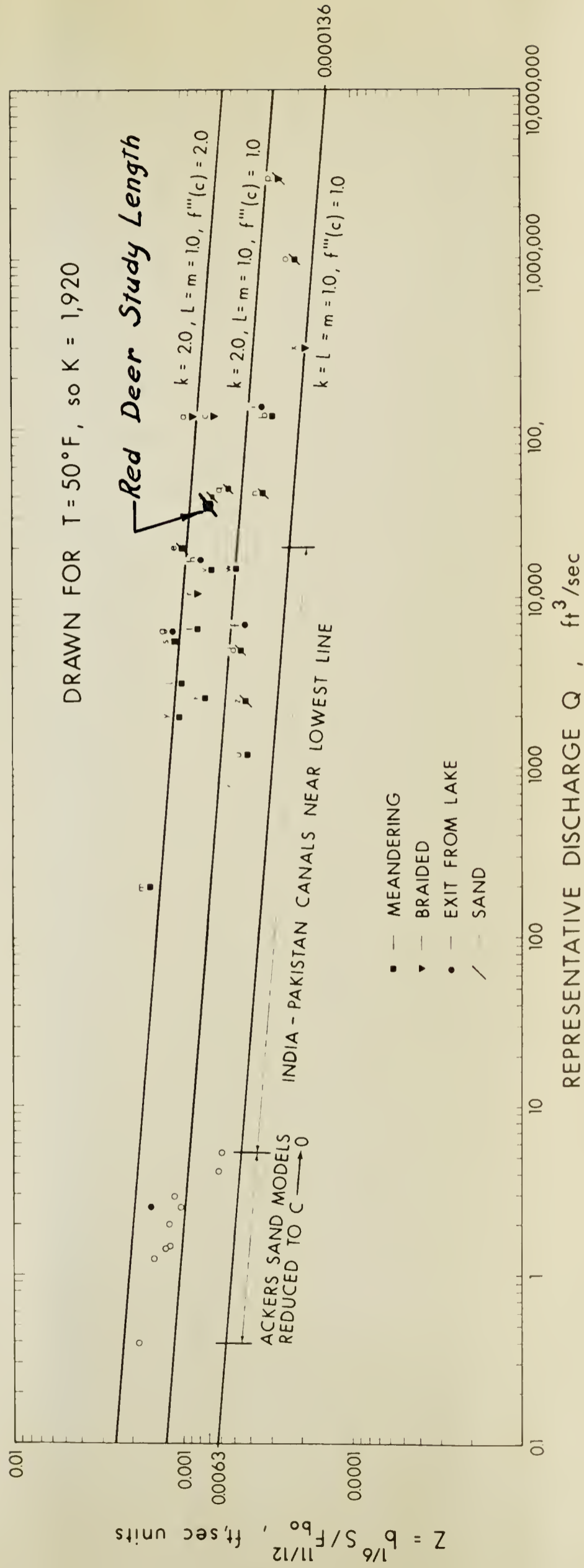
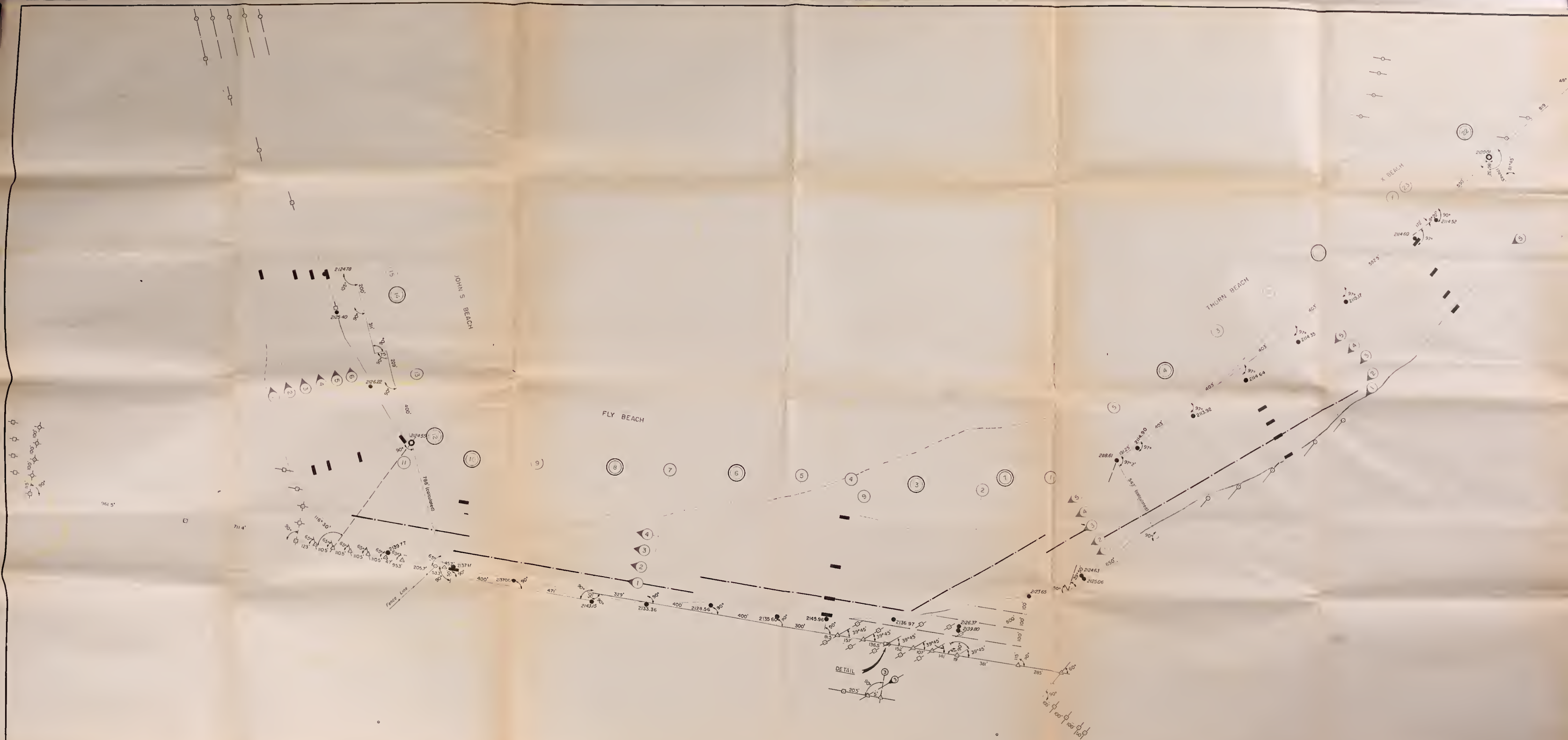
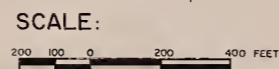
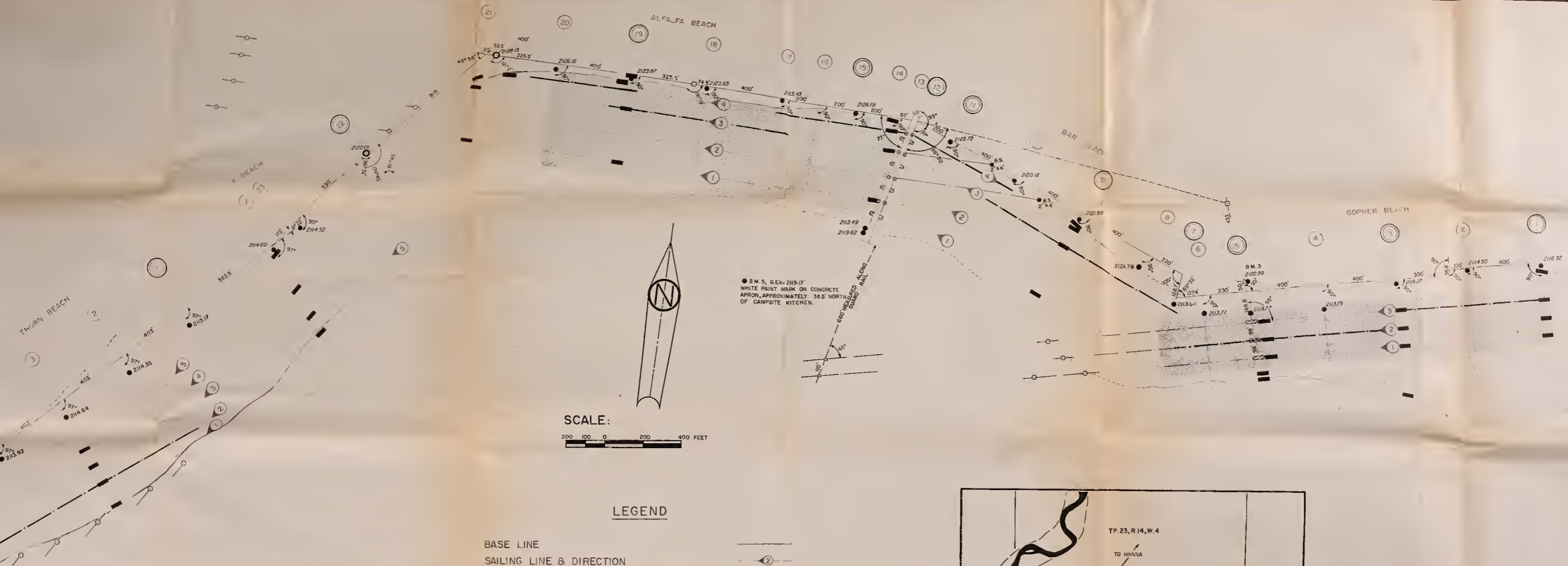


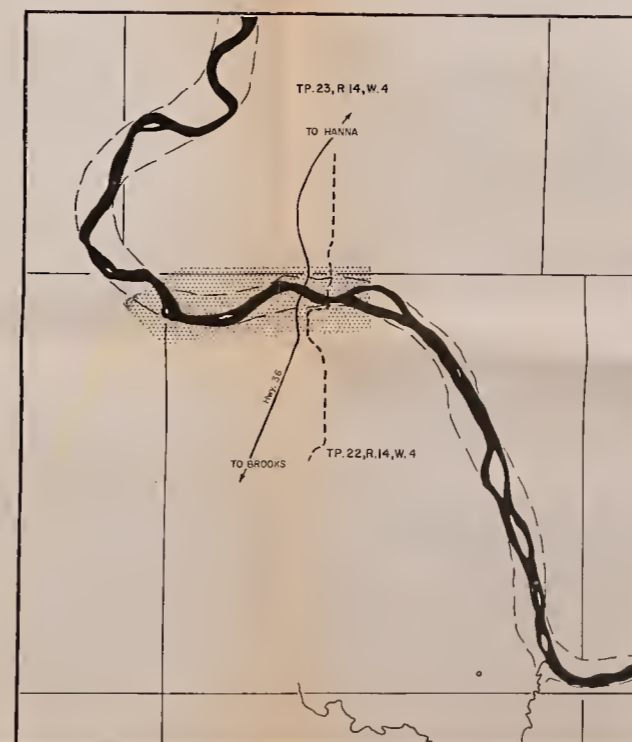
FIGURE 5.4





LEGEND

- | | |
|---|---|
| BASE LINE | — |
| SAILING LINE & DIRECTION | ② |
| FIX LINE | ④ |
| SAMPLING POINTS FOR BED & BANK MATERIALS | — |
| POST SETTING (3" DIAM., RED & WHITE) | — |
| HUB SETTING (4" x 4") | — |
| IRON PIN SETTING | — |
| TRANSIT POINT (9" RED CROSS ON BRIDGE DECK) | — |
| GEODETIC ELEVATION (TEMPORARY BENCH MARK) | ● |
| BRIDGE PIERS | — |
| LOCATION OF THE TEST REACH | — |
| SURVEYED CROSS-SECTION LOCATIONS | ③ |
| SAILING LINES IN DEEP WATER
(APPROX. THALWEG LINE OF FIG. 4.2) | — |
| AREA COVERED BY VOLUMETRIC BALANCE CALCULATION | — |



RED DEER
RIVER
AT
NORTH DUCHESS BRIDGE
SUMMER 1964 RIVER STUDY
HORIZONTAL CONTROL SURVEY
MAP No. 1

B29833